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Customer Discovery Best Practice for Understanding Siloxane Nuisance in Digester/Landfill Gas: A Journey from ISU Innovation Corps Spring 2018 Cohort to National Science Foundation (NSF) Innovation Corps (I - Corps) Program Spring 2019 Cohort Nashville

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**Customer Discovery Best Practice for Understanding Siloxane Nuisance in
Digester/Landfill Gas: A Journey from ISU Innovation Corps Spring 2018 Cohort to
National Science Foundation (NSF) Innovation Corps (I - Corps) Program Spring 2019
Cohort Nashville**

by

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A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Civil Engineering (Environmental Engineering)

Program of Study Committee:

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Ames, Iowa

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ABSTRACT

The purpose of this creative component is to tell the journey of our research in the form of customer discovery from ISU I Corps Cohort spring 2018 to NSF National Innovation Corps spring 2019. The use of siloxanes is increasing everyday due to the physiochemical properties that are appropriate to be included in the formulations of a large variety of consumer products. The aim of this creative component is to provide the current state of knowledge concerning the presence of siloxanes in digester/landfill gas. ESF Environmental Solutions through participation in NSF National Innovation Corps conducted 110 customer discovery interviews across 15 U.S. states. The interview question to different customer archetype in WWTP's and landfill enterprise consisted of asking them the problems faced during energy generation. Over the journey of interviews, it was learnt that siloxane nuisance affects the operation and economy of energy generation equipment in the form of increased maintenance and downtime. The renewed interest of industry in biogas pretreatment is primarily owing to the Renewable Identification Number (RIN) credits which is a currency of Renewable Fuel Standards (RFS). Payback period is the main concerning factor for industry prior to technology adoption. Biogas pretreatment for RNG is being attributed to economic benefits in the form of decreased engine maintenance costs and environmental credits in the form of RINs.

CHAPTER 1. INTRODUCTION

Background

The depletion of the conventional energy resources e.g., coal, oil etc. has created a trend of development of alternative energy resources. Intensification of global warming is the primary reason behind it (Shen et al. 2018). Existing infrastructure of fuel is already facing severe constraints from the perspective of environment and resource. Available reserves of fossil gas and oil is expected to last for 40-60 years. Over the period of time, as the exploitation of oil becomes more difficult it would subsequently increase the oil price in the world market. Greenhouse gases are particularly responsible for the direct pressure towards current coal and oil based infrastructure. It is foreseen that the concern for protecting environment would further dramatically increase the importance of use of sustainable fuels and greenhouse gas neutral power generation in the immediate future. With respect to the exigent concerns owing to greenhouse gas, one opportunity is to use biogas has strongly emerged (Kajolinna et al., 2015). The global drive towards sustainability has resulted in an increasing trend towards the use of biogas (Gersen et al. 2018).

International community has fully understood the effective role biogas technology can play in easing the international energy crises and optimizing the structure of international energy supply. Recycling of resources and energy in solid waste field is no longer a compliance mechanism however, has become a concern and consensus in the environmental field (Angelidaki et al. 2018). Biogases is mainly a renewable energy resource which can be produced by means of anaerobic digestion of biogas (AD) and landfill gas (LFG). Anaerobic digestion through anaerobic organisms includes municipal waste, sewage waste, manure, agricultural waste, food waste, etc. The main constituents of biogas are methane (47-65%) and carbon

dioxide (30-40%), and contains smaller quantities of nitrogen (< 1%), oxygen, and hydrogen; volatile organic including sulfur compounds, halogenated compounds, and organic silicon compounds. It is a green, environmental, and valuable renewable fuel (Bak et al., 2019; Shen et al., 2018; Abatzoglou and Boivin 2010; Ajhar et al. 2012; Souza et al. 2013).

Methane (CH_4) is identified as a greenhouse gas, and the effect produced by it is approximately 21 times higher than that of carbon dioxide (CO_2). Utilization of biogas would significantly reduce methane and other emissions from biogas being emitted to the atmosphere. This would positively impact the quality of air. The calorific value of biogas is $35\text{-}44 \text{ MJ/Nm}^3$ which is almost similar to that of LPG (liquified petroleum gas) and diesel kerosene and higher than other sources of energy like wood and coal (Hepburn, 2014). The high heat content of biogas makes conversion of biogas to heat/electricity possible (Gao et al. 2017; Grando et al. 2017; Miltner et al. 2017).

Biogas is used as a direct heat, co-generation, and in the recent years upgrading it to biomethane and injecting it in an existing natural gas grid is gaining momentum. The undesirable chemical constituents present in biogas such as hydrogen sulfide (H_2S), ammonia (NH_3), halogenated hydrocarbon, and siloxane, have the potential to cause corrosion, wear and tear, and damage to the boiler systems/internal combustion (IC) engine components (energy conversion systems) (Abatzoglou and Boivin 2010; Elwell et al. 2018; Kuhn et al. 2017). Amongst the chemicals mentioned above, siloxanes have the most detrimental effect on the utilization of biogases as heat in the boilers or electricity generation with IC engines or microturbines.

CHAPTER 2. ENTER “SILOXANES”

What is “Siloxane” all about?

Siloxane is a generic term for the class of compounds commonly found in consumer products with a silicon-oxygen backbone and organic side chains commonly called volatile methyl siloxanes (VMS). Five siloxane compounds in particular are a concern in digester and landfill gas due to their prevalence and volatility. They are linear compounds: hexamethyldisiloxane, $C_6H_{18}OSi_2$ (L2), octamethyltrisiloxane, $C_8H_{24}O_2Si_3$, (L3), and decamethylterasiloxane, $C_{10}H_{30}O_3Si_4$ (L4), and two are cyclic compounds: octamethylcyclotetrasiloxane, $C_8H_{24}O_4Si_4$, (D4) and decamethylcyclopentasiloxane, $C_{10}H_{30}O_5Si_5$ (D5). When gas containing these compounds is combusted, the siloxanes are oxidized to SiO_2 and microcrystalline quartz which coat post-combustion surfaces causing abrasion and other operating and maintenance nuisances. The prevalence of siloxanes in consumer products is due to their excellent qualities such as lack of color and odor, aiding in delivery and spread rate due to their hydrophobicity, thermal stability, low toxicity, and protection of active ingredients due to their low heat capacity and lack of chemical reactivity (Capela et al., 2016; Capela et al., 2017; Franco and Egmond, 2019). They can be found in products such as detergents, pharmaceuticals, cosmetics, lipstick, hair conditioner, paper coatings, and adhesives (Papurello et al., 2019). There is a growing concern that these compounds may not be as consumer and environmentally friendly as once thought (Mojsiewicz-Pienkowska and Krenczkowska, 2018), and the European Union has adopted legislation in 2018 to restrict the use of siloxanes (specifically, D5) to less than 0.1% by weight in products considered “wash-off” cosmetics and products such as hair conditioners. This is a proposed legislation that would extend this restriction to “leave-on” products as well (Franco and Edmund, 2019).

Siloxanes in digester and landfill gas cause operational problems for internal combustion (IC) engines, microturbines, fuel cells, and boilers. Once combustion takes place, the oxidized silica containing combustion gases cause silicates, e.g., silicone dioxide and microcrystalline quartz to form a coating on all surfaces. In an IC engine this coating occurs on cylinders, pistons, rings, valves, and valve sleeves. Catalytic converters can also be poisoned with the silicates in exhaust gases. Electricity production goes down as the coating affects heat transfer, lubrication, engine timing, and engine efficiency. Scale build-up can also come loose and cause blockages or other mechanical problems. Ultimately, the damage to the internal working of engines can lead to major mechanical failure. Engine operators and maintenance personnel are often left with the choice of more frequent engine maintenance (oil changes, head repair and replacement, and major engine overhauls) which results in system downtime and loss of revenue, or, to install an expensive siloxane removal system (Ajhar, 2010).

Understanding “siloxane nuisance”: What does the industry really want?

The problem evident through interviews as an I-Corps team was the need for an effective and efficient removal of contaminants prior to electricity generation or pipeline injection which would meet engine and pipeline quality standards. The common pain points shared by interviewees clearly implied the absence of economic siloxane abatement technologies prior to electricity generation or pipeline injection was the biggest hindrance in production of energy from waste gas. The interviewees advocated that absence of siloxanes in digester and landfill gas in the process of electricity generation would significantly reduce the engine maintenance costs. A clean gas would result in an increased uptime for electricity producers and alleviate concerns for renewable natural gas for systems injecting in the pipeline. Economic digester and landfill gas pre-treatment processes would further sustain the interest of investors as they would

foresee a lucrative payback period. The critical pain points shared by the interviewees aided in creating clear-cut visual understanding of technological innovation which can meet 100 percent of the market needs.



Figure 1: Damaged piston heads with a layer of siloxane coating (Seattle, WA) (I Corps Customer Discovery Interviews, 2019)



Figure 2: Hydrogen sulfide slag (precipitates) at boiler exhaust (Fort Dodge, IA) (I Corps Customer Discovery Interviews, 2019)



Figure 3: Sulfur precipitates (yellow coding) on exhaust pipes (Fort Dodge, IA) (I Corps Customer Discovery Interviews, 2019)



Figure 4: Siloxane built-up on engines in Malta (Ellis, 2020)

Engine-generator companies like Caterpillar, Jenbacher, Waukesha, and Deutz (Jenbacher and Waukesha are now owned by INNIO as of July 2019) have engine specification limits for siloxanes. Siloxane limits (mg/m³) for biogas for engine/microturbine manufacturers is reported in Table 1.

Table 1. Manufacturer Siloxane Limits (Wheless and Pierce, 2004)

Engine Manufacturer	Siloxane limit: mg/m ³ in Biogas
Caterpillar	28
Jenbacher	10
Waukesha	25
Deutz	5
Solar Turbines	0.1
IR Microturbines	0.06
Capstone Microturbines	0.03

Previous experimental results (Siefers, 2010) show that significant siloxane removal potential exists using tire rubber media, but the system needs to be optimized to reach some of the strict limits of some microturbines. Based upon the I Corps - customer discovery interviews, it is apparent that engine downtime is a severe punishment for the wastewater treatment plant or landfill gas to energy operators. Meeting engines/microturbines siloxane limits would result in decreased engine maintenance as well engine uptime would increase which would have economic benefits. Pipeline injection companies have stringent requirements for the quality of RNG being transported through the pipelines. RNG of the highest quality devoid of siloxanes and other impurities would result in operators getting market for the RNG produced. RNG has tremendous economic benefits in comparison to co-generation (ISU, 2019). The main purpose of this project lies in projecting waste tire rubber as an economical alternative to expensive activated carbon. Reduction in media costs incurred can have significant impact on the economy of the project.

One of the interviewees operating the engine-generator sets at the Wastewater Treatment Plant in Baltimore, MD (ISU, 2019) indicated that it costs them approximately \$50,000 to replace heads every 10,000 hours. A total rebuild is \$300,000. IC engines running on clean gas are rebuilt every 40,000 – 60,000 hours with siloxane in the biogas the rebuild interval shortens to 7000 - 8000 hours of operation. The economic investment required and tightening emissions regulations combined puts an onus on them to find effective ways to deal with the contaminants in biogas.

One of the principal partners at a leading environmental consulting firm in Des Moines, IA (ISU, 2019) stated that from an economic perspective cogeneration projects are difficult to recoup the 5.5 to 7.5 cents/kWh due to low electricity rates in various states in the

U.S. According to the interviewee, electricity prices in Australia are closer to 25 cents/kWh which makes co-generation more attractive. Australia has something in the construction industry called the BOOM market which stands for build, own, operate, and maintain, and cogeneration projects built and operated under this program can typically be paid off in 2 years. This short payback period has increased interest in these types of projects from investors.

CHAPTER 3. ISU INNOVATION CORPS (I-CORPS) JOURNEY

The National Science Foundation Innovation Corps (I-Corps) is an initiative to transition NSF funded research through from the laboratory to a product in the market place. The I-Corps sites act as a training ground for faculty, postdoctoral, graduate, and undergraduate students to learn how to increase the impact of their research through understanding and exploring the commercial potential of their research and technology (Iowa State I Corps Program, 2018).

Iowa State University became an I-Corps site in Fall 2017. The I-Corps program at Iowa State is a collaboration between the Office of the Vice President for Research (VPR) and the Office of Economic Development and Industry Relations (EDIR). The aim of Iowa State's I-Corps is to inculcate a stronger and more pervasive culture of entrepreneurship and innovation across the entire campus community (Iowa State I Corps Program, 2018). The focus through the program is on translating discoveries which reflects its strength in biorenewables, material science, agriculture, engineering, food and nutrition, and veterinary medicine. The clear motive of the program is to enhance entrepreneurship and innovation which is already happening across Iowa State campus. Fostering connections with other Midwest I-Corps sites would further help the faculty and students in collaborations and expertise. This would help strengthen the innovation fabric of U.S.

ISU Innovation Corps Spring 2018 Cohort

ISU has designed a four week curriculum which solely focusses on the “customer discovery” process. It supports the transition of devices, processes, ideas, or intellectual activities into the marketplace. The above things can be recognized by way of identifying funding sources to support additional research like SBIR, PFI (Partnership for Innovation) - Technology Translation (TT) etc., licensing agreements, or start-up businesses.

Under the I-Corps Program there should be a team comprising of Entrepreneurial Lead: Graduate student or postdoc and Academic Lead which is also referred to as Technical Lead (TL) or Principal Investigator (PI) which comprises of faculty member or other qualified scientist. ISU I-Corps site offers first-hand industry experience and entrepreneurial training to the participating teams. The ISU I-Corps site also provides networking opportunities, guidance, infrastructure, and resources for exploration of commercialization opportunities.

Sakhalkar (Entrepreneurial Lead) and Ellis (Technical Lead) participated in ISU I-Corps Site program after completing the online application. The team was further selected for second round after reviewing of the online application. Sakhalkar (Entrepreneurial Lead) was further requested to make a presentation to the review panel.

Initial Idea of Participating Team (Justification & Objectives)

Digester/landfill gas generation and its utilization as a fuel for electricity is a viable alternative used in different parts of U.S. and across the world. A major challenge to the use of digester/landfill gas comes from trace contaminants, namely ‘silica containing compounds’ called siloxanes. Silicones are widely used in consumer goods in part, because they are environmental friendly and have many useful properties. Unfortunately, silicone, once discarded, can volatilize into the gas phase as siloxane in landfills. The difficulty stems from digester/landfill gas combustion where siloxanes are further converted to silicon dioxide, a glass like substance that results in reduced engine efficiency, increased scour and abrasion, reduced heat transfer, and acceleration of equipment deterioration (Ajhar et al., 2010). Equipment specifications for cogeneration engines require siloxane concentration between 5 and 28 mg/m³ (Wheless and Pierce, 2004). Landfill gas devoid of siloxanes will greatly reduce the maintenance costs of engine generators. It will encourage more landfills and wastewater treatment plants (WWTP) to

generate electricity, thereby increasing the energy production from biorenewables.

The objective of laboratory research with ‘siloxanes’ under Dr. Ellis research group was to evaluate siloxane removal efficiency from digester/landfill gas using the smallest size fraction of rubber particles from shredded scrap tires (termed waste tire rubber particles - WTRP) and identify design and operating conditions that lead to not less than 98 percent siloxane removal efficiency and a siloxane concentration (D4 +D5) in the landfill gas less than 0.1 mg/m³ (limit recommended for electricity generation in microturbines) (Wheless and Pierce, 2004). The premise for this research objective is the discovery during preliminary testing that FRPM (fine rubber particle media) achieved 98.3 and 99.7 percent removal of siloxanes (D4 and D5) in a scrubber designed to remove hydrogen sulfide in biogas from a municipal digester (Siefers, 2010).

Benefits/Outcomes/Intentions of “Siloxane Analysis Laboratory Setup Experimental Research” (Dr. Timothy Ellis research group)

- a. Siloxane removal as a method to extend the operating period of the engine generators between maintenance intervals (reducing downtime).
- b. Development of a novel siloxane adsorption process to clean digester/landfill gas by means of fine rubber particles from scrap tires which highlights the tremendous potential to bind siloxanes and provide the basis for the proposed research (removal of siloxanes from digester/landfill gas prior to energy generation using scrap waste tire rubber particles).
- c. Development of marketable tire reuse technology that achieves a capital and operating cost of 50-80 percent of the cost of using activated carbon or silica gel adsorption technologies, verifying fine rubber particles as an economical and sustainable adsorbent.

The criteria of presentation to the review panel consisted of two conditions. First is, the presentation shall not exceed three minutes. Second is, the presentation should have three slides only. The first one, would consist of names of participating group members. Second one, should speak about the issue to be addressed. Third one, should speak of potential market and commercialization potential. There would be a two minutes question-answer round after the presentation.

ISU I-Corps Qualifying Pitch

Figure 5. shows the “Siloxane” issue addressed through problem with siloxanes (siloxane causes wear and tear of IC engines), objectives of the proposed research with pretreatment of digester/landfill gas for siloxanes which would form the basis of future business development, and technology to be developed (Intellectual Merit) which consists of application of waste tire rubber particles (WTRP) prior to combustion of digester/landfill gas in a scrubber system to remove in excess of 98 percent of siloxanes from the raw gas.

Enhancing **BIOGAS (LANDFILL & DOMESTIC WASTE WATER TREATMENT PLANTS)** Quality For Electricity Generation Using **WASTE TIRE RUBBER PARTICLES (\$\$\$)** For **SILOXANE** Control

- **Source**
Siloxane
- **Form**
Gaseous
- **Problem**
Affects engine generators
- **Objective**
Evaluation of siloxane removal efficiency from biogas using waste tire rubber particles(WTRP) from shredded scrap tires
- **Technology**
Based on results obtained at Ames WPCF during field study of hydrogen sulfide removal, sampling the biogas before and after the scrubber system using WTRP apparently removed in excess of 98% siloxanes from the Biogas



Puente Hills

Figure 5: Slide No. 2 (siloxane nuisance in landfills)

The making of Figure 6. (potential market and commercialization potential) involved finding the footprint of landfills and wastewater treatment plants (WWTP's) and further identifying the facilities having digester/landfill gas to energy (LFE) already operational and in the process of construction in U.S. There are approximately 2000 operational landfills in U.S. and 10,000 old landfills which have been closed or capped (EPA - Landfill Methane Outreach Program, 2018). Landfills have to be monitored 20-30 years after closure as well they continue to generate landfill gas which has economic value attached to it. With operational landfills they can be leased on 30-40 year contract with monitoring and utilization of landfill gas for renewable natural gas (RNG) and/or electricity. This allows enough time to recover the capital investment and further incur significant profits.

Out of 14,748 active wastewater treatment plants in U.S., 1200 have anaerobic digesters (AD) of which 180 plants generate electricity from digester gas (Center for Sustainable Systems, 2019). The commercialization potential lies with addressing two important things: First is, development of economical and effective siloxane adsorption process which can be accepted in the market. Second is, developing an alternative to expensive siloxane adsorption media - activated carbon (AC).

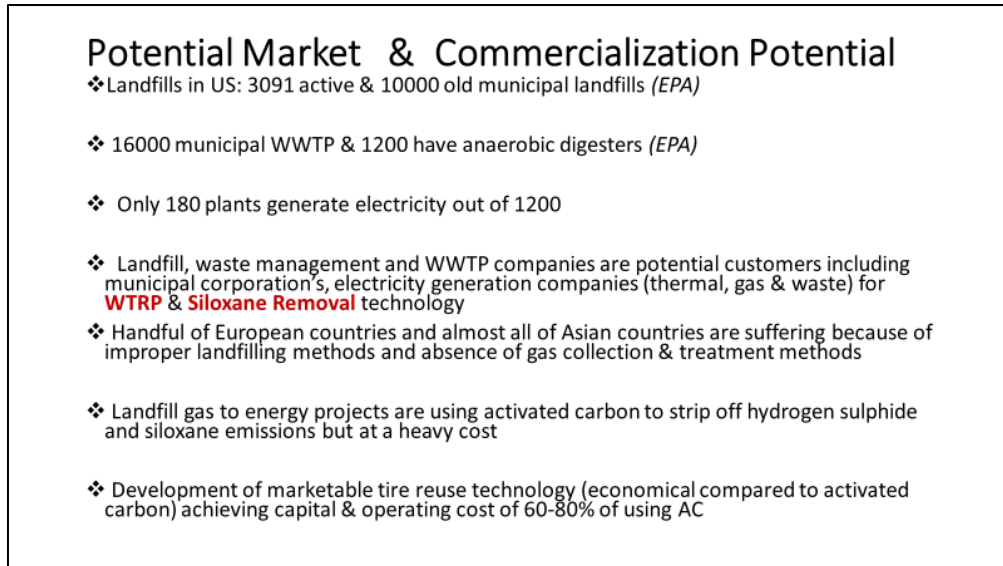


Figure 6: Slide No. 3 (potential market & commercialization potential)

ISU I-Corps Curriculum Program

The team comprising of Sakhalkar (EL) and Ellis (TL) were selected and further participated in Spring 2018 cohort. The team was named “Group Siloxane”. The ISU I-Corps Site ID is 1734820.

Pre-course work

Each team member of group Siloxane was provided with two books which would aid them in creative learning and successful completion of ISU I-Corps cohort, Business Model Generation and The Startup Owner’s Manual by Steve Blank. Each team over the 4 week duration of cohort were required to conduct 15 customer discovery interviews as a part of the get to know process. The interviews had to be recorded on LaunchPad Central.

Steve Blank is widely credited for developing the customer development method that launched the lean startup movement. According to his methodology the startups are not

miniature version of large companies but they require their own set of tools, techniques, and processes to be successful. The Lean Launchpad class of Steve Blank been taught at National Science Foundation (NSF) Innovation Corps or I-Corps has become the benchmark for commercialization of all federal research. Customer development methodology developed by Steve Blank has become the cornerstone of the lean startup movement.

Through LaunchPad Central the participating were given access to course videos of Steve Blank. The purpose of the videos is to understand the importance of customer discovery in business development. Insights learnt through course videos on LaunchPad Central have been formulated in the form of 11 tables by Sakhalkar (EL) over the course of the thesis. The videos were an eyeopener in the form of understanding thoroughly the different components of business model canvas (BMC).

Customer Discovery Best Practice

Table 2. Pre-planning, interviewing, and analysis & insight (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	Pre-planning stage involves identifying people with whom you will talk to
2.	In pre-planning stage we should approach maximum people through linkdin, Facebook or other social media
3.	It is advisable to interview a person in the middle of a company as there is high possibility of getting more interviews with him
4.	Face to face interviews are the best as they help us watch the body language of the customer
5.	What should have I asked you, should always be the last question as it can generate multiple possibilities
6.	Customer discovery cannot be outsourced as discovery is not a focused group
7.	Validating your initial hypothesis can help you iterate your pivot
8.	Designing pass/fail tests to validate hypothesis can be beneficial
9.	While interviewing it is better to be clear, concise and extremely communicative
10.	Customer discovery is about coming prepared to listen because they are important
11.	An interviewer should get comfortable in discovery as well not be rigid in conversations
12.	Being open to surprises and insights and recording them
13.	Testing the solution involves series of untested hypothesis and assumptions which helps to develop the product market fit

14.	Testing the solution is about converting guesses into facts
15.	Sizing the opportunity, understanding the market type and competition is important
16.	Interviewer should try to understand the details of customer archetype
17.	Understanding their day, interests & interactions and getting complete view of customer is important
18.	Validating your problem must be followed with validating the solution
19.	Addressing the solutions by creating a demo can be impressive in customer discovery
20.	Customer discovery is not just PowerPoint slides but series of untested hypothesis
21.	Interviewer should make a serious attempt to understand the pain points of the customer
22.	While taking group interviews the roles of interviewers should always be predetermined
23.	The best possible way to have empathy for customers is by being in their shoes
24.	In existing market startup setup the scope of questions is high
25.	A visionary entrepreneur identifies a new market or a market which never exists
26.	Goal of collecting information from the customer is to become the customer
27.	Introducing yourself precisely is a key to start up the conversation
28.	Analysis & insight of the information obtained helps in developing product market fit, understanding customer archetype, whether minimum viable product (MVP) matches customer need, channels, partners, customer acquisition, activation & retention, costs, and metrics
29.	MVP is not a smaller version of the final product
30.	Getting out of the building and running an experiment is not an accounting problem
31.	Importance should be given to the people who are not using the product to help identify the reasons why they are not your customers

Lecture 1: What We Now Know

Table 3. Business model and customer development (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	Startups are smaller version of larger companies is a fallacy
2.	Large companies spend time executing whereas startups spend time searching
3.	No plan survives first contact with customers
4.	Planning before the first business plan requires strategy
5.	Business model canvas (BMC) organizes overthinking
6.	Instead of writing the operating plan and financial forecast first thing to be done is capturing all the hypothesis in BMC and once we find the model we can do the execution
7.	Old techniques for startups involved concept, development, testing, and finally launch.
8.	Waterfall development which involves the stages of: requirements, design, implementing, verify, and maintain is a fallacy as it takes into consideration that the we know the customer problem and hence the product feature as well
9.	Most startups fail from a lack of customers than from a failure of product development
10.	Most companies do not have processes to manage customer risk

11.	In customer development the first two stages of customer discovery and customer validation consists of a pivot which can be categorized as search phase. Customer creation and customer building is an execution phase.
12.	Customer development with agile development leads to product development
13.	Agile or waterfall development is based on continuous iterations
14.	In a startup, founders spending 20 percent of their time outside the building understanding customer problems and needs and figuring out how that matches with the feature set you are building is critical

Lecture 1.5A: Business Models and Customer Development

Table 4. Business Model Canvas (BMC) (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	According to Steve Blank, a startup is a temporary organization designed in such a manner so as to search for a business model which is scalable and repeatable in nature
2.	A startup aims to begin a company
3.	Business model is a concept of how a company can create value for itself while it delivers products or services for customers
4.	Value proposition is a fancy word for products and services we are building
5.	Technology is just a part of value proposition. Customers do not care about your technology. Customers are trying to solve their problem.
6.	The customers do not exist to buy the product/service, we exist for them to provide it
7.	Distributing channels is all about delivering the value proposition to the customer segment
8.	Customer segments in BMC is how to get, keep and grow customers
9.	Revenue streams is the value customer is paying for the services availed
10.	Key resources consists of most essential holdings required to make business model operate
11.	Key partners and suppliers are not always required on day one for a startup
12.	Key activities are the actions needed to make business model functional
13.	Costs consists of entire costs involved in the process to operate business model

Lecture 1.5B: Business Models and Customer Development

Table 5. Customer Development Process (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	Business model canvas is a series of thoughtful first guesses. It helps to organize our thinking
2.	Pivot between customer discovery and customer validation through testing hypothesis will save the job of the resources be utilized in execution phase
3.	Customer discovery should be done by the founders in a startup

4.	Founder has the power to change the product, make pivots, and hear the customer feedback firsthand
5.	Customer development is testing the hypothesis from an implicit to an explicit
6.	MVP (minimum viable product) is to get a feedback so that we can proceed or add more features
7.	Pivot is what do you do when your customer hypothesis do not match your reality
8.	Pivot allows a founder to get out and make changes
9.	Pivots are a result of hypothesis testing and experimentation
10.	A pivot is a substantive change to one or more business model components
11.	Customer discovery process consists of: stating hypothesis and draw BMC, test the hypothesis, test the solution, and proceed or pivot
12.	Customer development process is an iterative circle
13.	Customer validation consists of: get ready to sell (obtain customers, activate, build a high fidelity MVP, build sales collateral, sales road map), get out of the building, develop positioning (develop corporate and product positioning before spending on PR agencies), and verify
14.	Market opportunity analysis consists of: identifying a customer and market need, size the market and competitors and assessing the growth potential
15.	Total available market is the total share of the opportunity
16.	Served available market is how big the opportunity would be for me ? It can be approximately quantified based on pricing and availability

Module 1

The videos provided of Steve Blank was of immense help in pre-preparation for participation in ISU I-Corps cohort. From Table 2. pre-planning, interviewing, and analysis & insight, Table 3. Business model and customer development, Table 4. Business Model Canvas (BMC) and Table 5. Customer Development Process different insights were learned. This led “Group Siloxane” to create their first ever business thesis and business model canvas (BMC).

First Business Thesis

1. Removal of siloxane from biogas stream for sustainable electricity generation and increasing engine life expectancy of electric generators.
2. Using scrap waste tire rubber particles as an adsorbent media for removal of siloxanes for maintaining better economy.

3. Increasing marketability potential of waste tires in U.S. and converting this expendable asset into a beneficiary one.

In the making of first BMC (see Figure 7.), two things were emphasized upon: unique value proposition (UVP) and customer segments. Municipal waste water treatment plants and landfilling companies are the entities which are the source of digester/landfill gas. Resource recovery plants were added to the customer segment from perspective of a place which sends the biodegradable resource to landfills which further converts to landfill gas. Thermal (coal fired) power plants was a general guess from the team owing to the removal (adsorbent) media used in the scrubbers for removal of impurities (contaminants).

The first value proposition of marketable tire product made from waste tire rubber particles which are cheaper than activated carbon had two objectives as part of the intellectual merit of the technology. First is, finding an economic replacement to activated carbon so that the costs of media replacement can be largely mitigated. As well, the process of siloxane removal can become more process efficient. Second is, use of waste tires which are a disposable resource and the generation of adsorbent media manufacturing businesses and employment opportunities.

The second value proposition of siloxane removal technology for clean and efficient biogas to generate uninterrupted electricity in landfills and municipal WWTP's was from the perspective that siloxane affects engine generator components and creates a variety of problems with maintenance and output which even at times increases the downtime of engine generators. A widely accepted siloxane removal process technology can address this issue. This would result in even more wastewater treatment plants (WWTP's) and landfills having anaerobic digesters (AD) technologies to process the digester/landfill gas prior to combustion and use it as a renewable natural gas (RNG) and/or to generate electricity.

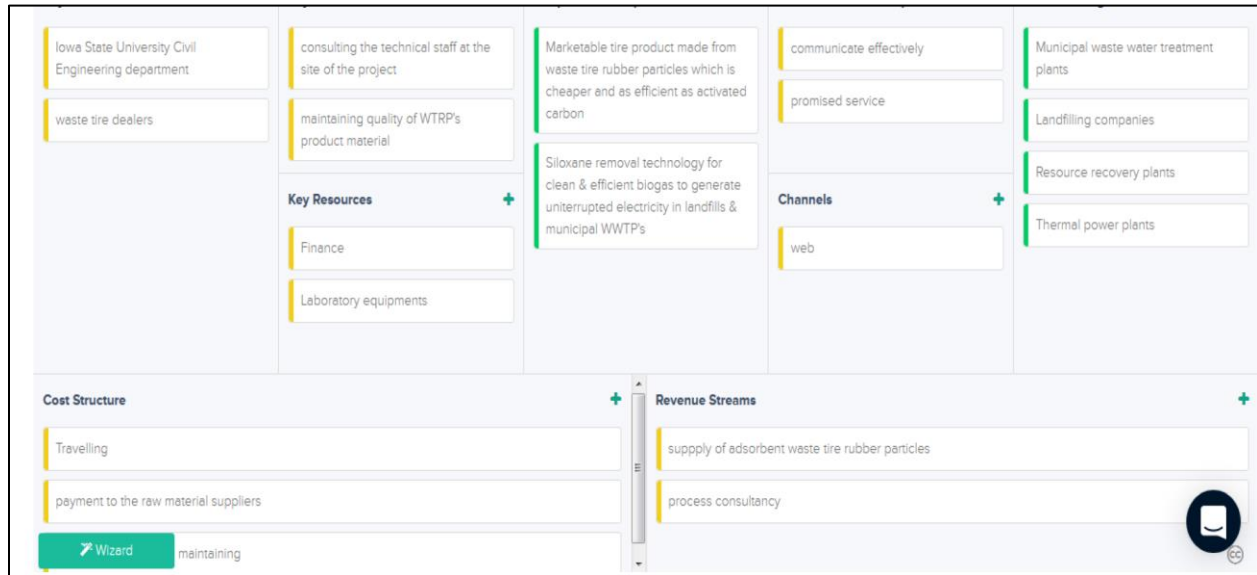


Figure 7: First Business Model Canvas – A Series of Untested Hypothesis

Module 2

Four customer discovery interview were conducted during week 1 including the director of a pharmaceutical company, the principal of waste management firm, the site engineer of a waste management company, and operator at Ames Water Pollution Control Facility (WPCF). The various insights and lesson learned from these phone interviews are as follows: there is a stark difference between “cold call” and “planned call”, introducing yourself in short is crucial, there are no regulations to flare gas, green dollars investment in wind energy in Midwest is a deterrent for generating renewable energy credits from anaerobic digesters, biogas greater than 100,000 tons of solid waste capacity per year of landfills is important for economic reasons, and wastewater treatment plants generating biogas suffer greatly from the siloxane problem and change oil frequently to reduce engine wear and tear (alternative remedy).

On a personal note as an entrepreneurial lead (EL) from lessons learned through interviews:

“I realized that I have to keep customers engaged even if I hear they are not doing anything about siloxanes. Take their email id and drop a mail which I did. Reaction of the potential customers changes after telling them you are a Ph.D. student and your noble intention of removing siloxane from gas stream. There is tremendous potential, technical staff (mid-level management employees) should only be contacted”. (Lesson: Week 2)

In Figure 8. from the business model canvas it can be seen that value proposition of siloxane removal technology for enhancing the life of engine generators and marketable scrap waste tire rubber particles as an efficient and cheaper adsorbent was further refined to meet the customer segment of landfilling and waste management companies/enterprises and municipal wastewater treatment plants. An effort was made by group siloxane to create a perfect product-market fit. Enhanced life of engine generators is the first priority of the customers. If the process of removal of siloxanes is made more economical then it would be a win-win situation.

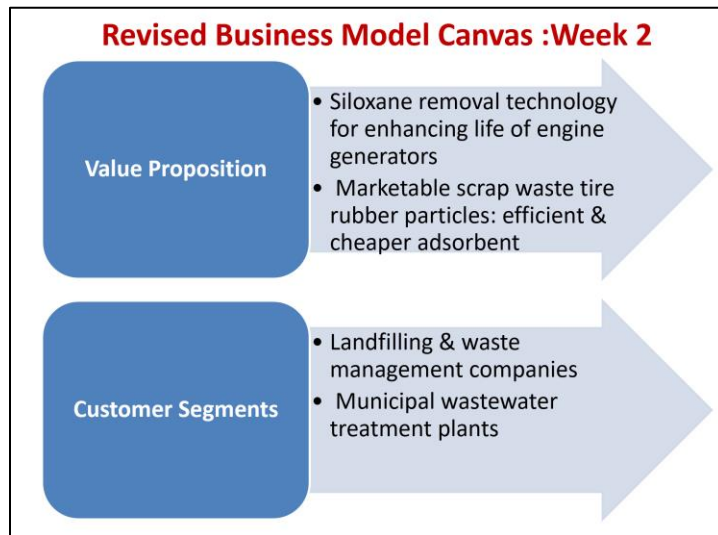


Figure 8: Revised BMC - Week 2

Business Ecosystem in Figure 9. is of three parts: value chain - building a marketable product for the customer, workflow - process efficiency of the siloxane through the startup team (spin off company), and decision making - taking all the stakeholders and the startup team into account.

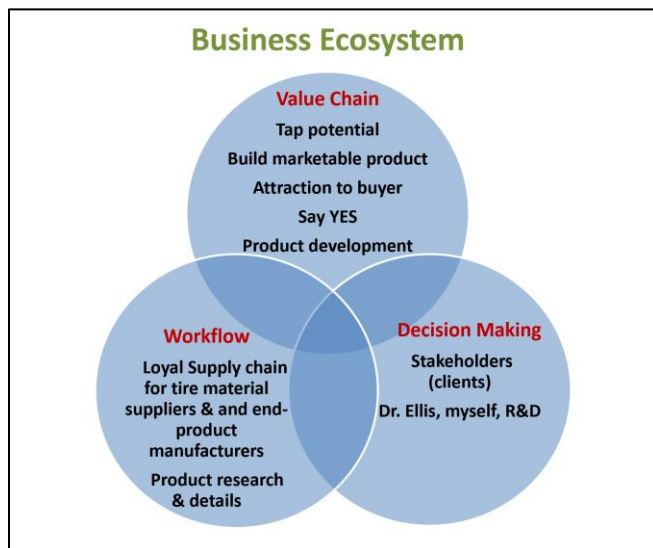


Figure 9: Business Ecosystem

Module 3

From lessons learned from the previous interview, the EL (Sakhalkar) was much better prepared for the interviews in week 2. In this week 6 phone interviews were conducted in the State of Pennsylvania (PA). All the interviews were with mid-level staff of landfilling companies having landfill gas to energy facility in-situ. The things done differently this week during interview process was after giving a short introduction, the interviewees were asked about their story (version) of problems faced by engines in digester/landfill gas combustion cycle. The points were noted comprehensively. In the process a rapport was developed with the potential customer.

One interesting thing learned this week was the validation of proposed hypothesis that siloxane does affect the output of internal combustion (IC) engines. The problems faced in the process of combustion of landfill gas has tremendous economic ramifications. The process ultimately is more expensive than the output produced. This has created a negative market sentiment that LFE projects are less profit making.

Business Model Canvas remained the same as previous week except the customer segment was narrowed to landfill gas to energy companies.

Figure 10. Product-Market Fit shows the counterbalance between need and the solution. Product market fit which is balance between customer discovery and customer validation (both are a part of search phase of the startup beyond which the startup can further proceed with customer creation and customer building process). When the product market fit is not achieved then iterations can be done or else a necessary pivot (changing hypothesis) can be considered.

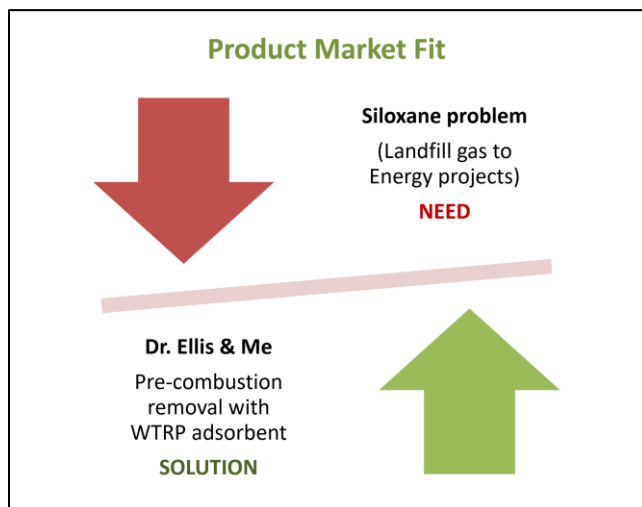


Figure 10: Product Market fit

The petal diagram (see Figure 11.) can be something that drives your business model canvas. The petals of the diagram shows the different customer segments. The customers come

from each of these segments. A petal diagram helps us to identify our first potential customer segment on the business model canvas.

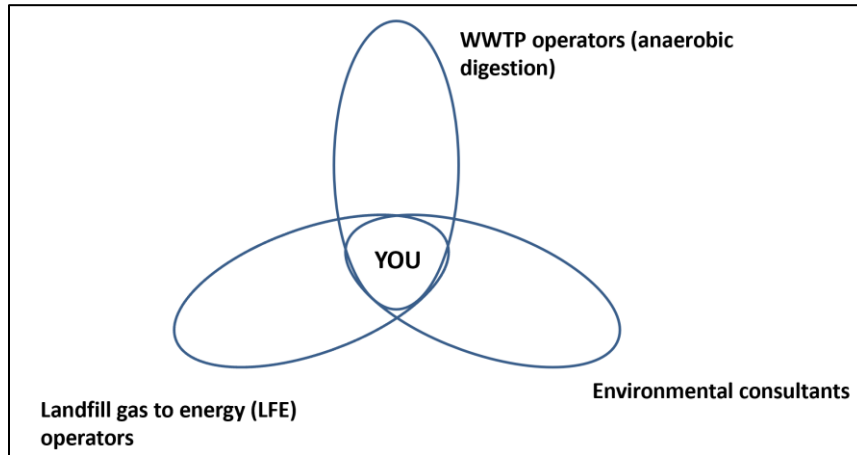


Figure 11: Petal Diagram

Module 4

Twenty six customer discovery interviews conducted by week 4. Business Model Canvas (BMC) remained the same as in week 2. A couple of insights learned over the week were: there is a tremendous vacuum for effective siloxane treatment technologies, an alternative to treatment is to change oil frequently to address siloxane issue, siloxanes contributed to reduced heat transfers and heat problems, in addition to the engine components getting severely affected by siloxanes it also ends up clogging the exhaust and pipes, soot formed in the combustion zones results in reduced heat transfer (kWh impacted), coating of siloxanes formed inside engine generators/boilers increases the maintenance and subsequently the economic (energy) losses through downtime increases, siloxane problems in the LFE market is taking focus off of sustainable waste management practices, and landfill operators are open, excited and receptive to the idea of removal of siloxane using scrap waste tire rubber particles.

Summary of I-Corps Journey

The market research study (customer discovery) which generated 26 phone interviews covering

different market segments from wastewater treatment plant operators, company director, and landfill operators in Iowa and Pennsylvania provided firsthand experience for the entrepreneurial lead Sakhalkar.

Table 6. Most common interview replies

Site	Response to siloxane nuisance during electricity generation
1	<ul style="list-style-type: none"> ▪ We keep changing oil in the generators every 350 hours of operation. ▪ Damage to the engines is partially mitigated by changing oil.
2	<ul style="list-style-type: none"> ▪ Siloxanes clog pipes, heads & exhaust. ▪ Engine misfires because of higher back pressures. ▪ Siloxane reduces the energy recovered.
3	<ul style="list-style-type: none"> ▪ Generators need to undergo maintenance continuously.
4	<ul style="list-style-type: none"> ▪ Siloxanes persist in co-generation with coal too. ▪ Forms coating inside generators and traps heat. ▪ Mixes with carbonaceous soot.
5	<ul style="list-style-type: none"> ▪ We keep changing parts continuously as we are into manufacturing too.
6	<ul style="list-style-type: none"> ▪ We had to switch from LFE to bio-CNG business as siloxanes affect profitability in small plants.

CHAPTER 4. NATIONAL SCIENCE FOUNDATION (NSF) INNOVATION CORPS (I - CORPS) PROGRAM SPRING 2019 COHORT NASHVILLE

Team “ESF Environmental Solutions” was selected to participate in NSF Innovation Corps Program in Spring 2019. The qualification process consisted of three stages: pre proposal, phone interview, and final proposal. According to the structure of the participating teams at NSF Innovation Corps, the team should consist of a Technical Lead, an Entrepreneurial Lead, and an Industry Mentor.

I-Corps Team

The proposing team consists of Sidhdav Sakhalkar as an Entrepreneurial Lead (EL), Timothy G. Ellis, Ph.D., P.E. as Technical Lead (TL), and Craig Forney, Ph.D. as I-Corps Team Mentor (IM).

Sidhdav D. Sakhalkar has been a doctoral student under Timothy Ellis (TL) in the Department of Civil, Construction and Environmental Engineering (CCEE) at Iowa State University (ISU) since August 2017. Mr. Sakhalkar has an undergraduate degree in Civil Engineering from University of Mumbai (India). In his undergraduate thesis he worked on the 3-S (speed, strength & safety) technology of building construction using geopanel formwork and perforated concrete blocks. The emphasis of the research was on construction of economic and efficient housing for low income groups. He holds a master’s (M.Sc.) degree in Energy & Environmental Engineering from the University of Sheffield, England. His dissertation project for his master’s involved comparing municipal solid waste and oil to select a better alternative for electricity generation. It involved mass burn incineration process to completely reduce the municipal solid waste to ash and utilizing the heat to generate electricity. Mr. Sakhalkar’s love for working in air pollution mitigation technologies related to municipal solid waste led him to work with Dr. Ellis as his Major Professor at ISU. Under the guidance of Dr. Ellis, Mr.

Sakhalkar successfully participated in the ISU I-Corps Site Program in February 2018. He presented the novel research concept “removal of siloxanes from landfill gas prior to electricity generation using scrap waste tire rubber particles” as a part of ISU I-Corps site program. Prior to coming to the U.S., Mr. Sakhalkar served as a lecturer in Structural Engineering in India for Guwahati College of Architecture for four years. He has also authored a book “Structures Simplified” for first year architecture students in India which covers the statics portion of engineering mechanics. Mr. Sakhalkar also actively guides undergraduate students at ISU in engineering mechanics. In Fall 2018 he was a teaching assistant for the engineering economic analysis and principles of environmental engineering classes, for which he received very positive feedback from students through the Center for Excellence in Learning and Teaching, ISU learning Communities, the Office of Multicultural Student Affairs, and the Student Government as a part of #CyThx initiative which acknowledges those in the teaching community who impact the life of students. Mr. Sakhalkar has two years of industry experience in the design and installation of biogas plants and solar photovoltaic projects.

Timothy G. Ellis, Ph.D., P.E. is an associate professor in the CCEE Department where he engages in teaching and research in environmental engineering. His major focus areas are biological wastewater treatment, resource and energy recovery from environmental systems, and air pollution control. He is currently a member of the advisory board for the Water Environment Research Journal and served as the editor-in-chief for the journal for a five-year period from 2013 through 2018. He participated in a Fulbright Scholarship at the University of Malta in 2014 where he developed a course in solid waste management and waste recovery. In addition, he has received numerous teaching, research, and service awards. He currently serves as the faculty advisor for the American Society of Civil Engineers (ASCE) student chapter. He has served as

the major professor for 8 doctoral students and 30 master's students during his 25-year tenure at ISU. In addition, he has significant industrial experience having worked for the City of Baltimore and Engineering Science (now Parsons Engineering Science) in Fairfax, VA and Abu Dhabi, U.A.E.

Craig Forney, Ph.D. is a Senior Commercialization Manager with the Iowa State University Research Foundation (ISURF) happily agreed to the request of Dr. Timothy Ellis to be an Industry Mentor (IM). Dr. Forney focuses on commercializing chemistry and materials science-related technologies discovered at ISU. Having obtained the Certified Licensing Professional from the Licensing Executive Society, Dr. Forney has served in this role since 2013. In addition to negotiating license agreements with companies ranging in size from startups to Fortune 100 corporations, Dr. Forney is involved in evaluating technologies for patentability and commercial relevance, developing commercialization and marketing strategies, and assisting with patent prosecution matters.

Teamwork and collaborations

In addition to individual qualifications, the proposing team members have established a strong working relationship which will ensure the success of the activities planned for this commercialization feasibility assessment with the support from the National I-Corps Teams Program. EL Sakhalkar and TL Ellis have worked together as a team in the first cohort of the ISU's I-Corps Site Program, which further motivated them to pursue the translation of their fundamental research to the marketplace. With the assistance of the ISU's I-Corps Site Program leadership, they were able to identify IM Forney who not only has extensive experience in intellectual property and technological transfer, which are all relevant to the proposed innovation, but also has a chemical engineering background, which connects well with potential target customers. In the past six months, EL, TL, and IM of the team have regularly met and

discussed various commercialization aspects of the discoveries made through the project. This has put the team in a unique position to systematically advance the developed proof-of-principle to proof-of-concept and prototype preparation based on the customer viability assessment that will be completed through the NSF-sponsored National I-Corps Teams Program.

Lineage of the Proposed Innovation

NSF Lineage. The proposing team was selected to join the second cohort of the ISU's I-Corps Site Program in February 2018. The EL and TL of the project participated in this program and satisfactorily completed all the tasks and requirements.

Intellectual Merits of Core Technology. Landfill gas generation and its utilization as a fuel for electricity is a viable alternative energy source used in different parts of United States and across the world. A major challenge to the use of landfill gas comes from trace contaminants, namely 'silica containing compounds' called siloxanes. Unfortunately, siloxane, once discarded, can volatilize into the gas phase in landfills. The difficulty stems from landfill gas combustion where siloxanes are converted to silicon dioxide, which is a glass like substance that reduces engine efficiency, reduces heat transfer, increases scour and abrasion, and accelerates equipment deterioration (Ajhar et al., 2010). The current cost to maintain an engine generator is approximately \$0.015 to \$0.02/kWh of electricity generated (ISU I-Corps customer discovery interviews, 2018). Landfill gas devoid of siloxanes will lower these maintenance costs significantly.

Our innovation is the development of a new siloxane adsorption process using waste tire rubber particles. Using this approach, the siloxane nuisance in landfill gas to electricity plants will be mitigated. In the U.S. approximately one tire per person every year is discarded. Currently, there are limited options for the reuse of the rubber material from these waste tires (e.g., crumb rubber used for landscaping and cushioning for athletic fields). The development of

an effective adsorption process using the smallest size fraction of waste tire rubber represents an exciting entrepreneurial opportunity to turn this waste product into a marketable adsorbent that can compete with activated carbon adsorption for siloxane control.

Commercial Opportunity. An initial study of the effectiveness of fine rubber particles from waste tires to remove siloxanes was performed during a field study of hydrogen sulfide removal at the Ames Water Pollution Control Facility (Siefers, 2010). This study demonstrated a siloxane removal efficiency greater than 98%. These preliminary results suggest that tire rubber particles of the correct size have a significant adsorption capacity for siloxanes that could be exploited in a landfill gas scrubber. In addition, early customer discovery efforts were conducted involving landfill gas to electricity (LFE) projects in Pennsylvania (Sakhalkar, 2018) through participation in the ISU I-Corps Site Program. Twenty-six landfill operators were interviewed as a part of testing the hypothesis that siloxane control is a major issue at landfill sites, especially those that use the gas to generate electricity. During these interviews it was apparent that siloxanes are a universal nuisance that increases the maintenance costs of engine generators. Landfills and domestic wastewater treatment plants would be the biggest beneficiaries of a solution for siloxane control. Customer discovery is required to understand the depth of the problem and needs of the industry, and to account for variations (e.g., size, geography, climate) in landfills and treatment plants across the U.S.

Description of the Potential Commercial Impact

The proposed technology is comprised of two main components: (1) Development of a novice siloxane adsorption process to clean landfill gas using fine rubber particles from scrap tires. (2) Development of a marketable tire reuse technology that achieves a capital and operating cost of 50-80% of the cost of using activated carbon or silica gel adsorption technologies, verifying the premise that fine rubber particles are an economical and sustainable adsorbent.

There are three potential markets that can be immediately targeted for the developed system (as a whole or individual components).

1. **Landfills:** At present, there are 2000 active landfills in U.S., out of which 953 have electricity generation (EPA - Landfill Methane Outreach Program, 2018). According to the EPA, 80 percent of the landfills generating electricity have reciprocating engines while the remainder have gas turbines or direct gas use. For landfills with reciprocating engines siloxane damage is mitigated by increasing the frequency of engine maintenance, replacement of engine components, and more frequent oil changes. Siloxane can reduce the energy output of the engines and increases the operation and maintenance costs. Profitability of small landfills is largely affected by this.
2. **Municipal wastewater treatment plants:** There are approximately 14,748 domestic wastewater treatment plants in U.S. serving about 75% of the U.S. population (Center for Sustainable Systems, 2019). Approximately 3 percent of electricity consumption in U.S. goes towards operation of wastewater treatment plants. Siloxane is an operational nuisance during electricity generation from digester gas (biogas) and siloxane control is a critical consideration in energy generation from wastewater treatment plants.
3. **Waste tire recyclers:** Other stakeholders identified in the LFE ecosystem include waste tire recyclers, who are potential suppliers of the raw materials for the siloxane adsorption process; this is hypothesized to be part of the channel for delivering the final product to the in-situ operations. Waste tire rubber particles as a competitive replacement to activated carbon will create a new segment for business opportunities in the Midwest and across the U.S.

National Science Foundation (NSF) Innovation Corps (I-Corps) Program

The requirements for enrollment of selected teams consist of:

1. The NSF selected Team should attend the program consisting of a Technical Lead, Entrepreneurial Lead, and Mentor.
2. Every member of a given Team must commit to minimum of 15 hours per week towards Customer Discovery.

Schedule of Program

Days and Times:

1. Kick-off workshop: May 6-8, 2019 (with a Reception on May 5)
2. 5 online classes: Tuesdays, 1 - 4:00 pm ET, May 14, 21, 28; June 4, 11
3. Closing workshop: June 20-21, 2019

Course Goals

1. Providing the I-Corps Team a realistic learning opportunity that would help them to ascertain the business prospects of their technology.
2. Empowering the Team with practical knowledge and confidence that would enable them to develop a clear go/no decision with regards to the commercial viability aspect of the project.
3. Enabling the Teams with know-how of additional funding sources through NSF as well developing a transitioning plan to move on from the technology to a product in the marketplace.

Course description

The course is designed in a certain way to provide I-Corps Teams with real-world experience to develop a know-how of successfully transferring knowledge into products and processes that would immensely benefit society. The Team will learn from talking to customers,

partners and the chaos which is encountered, uncertainty which is faced in the process of commercializing innovations and rolling out startup companies. NSF National Innovation Corps is all about getting out of the building and testing your hypothesis on customers. It is not about drafting a business plan, applying for a NSF Grant, request for proposals (RFP's) submission, or research paper. The commitment of the participating Teams in the program is solely needing to get out of their workplace and talk to customers which is, the non-negotiable requirement of the course.

Teams

It is a purely team-based class. Working as a group will enable the teams in turning their research and the ideas into a product or service which benefits the society. The teams will learn the technique of using a business model canvas (BMC) so as to brainstorm each part of the customer development and the enterprise. Each week the teams will face a new adventure as they talk to customers, test their hypothesis on different components of the business model and the customers. In the process of the course Teams will learn as to how the process of agile (active) development can assist them to iterate their product into something the prospective (future) clients will happily make use of and purchase. The Teams will also learn the different issues encountered in group work and the technique through which they can successfully build and manage their startup team.

Class Culture

The culture of startups is way noticeably different than the college culture. The class culture is developed in a way intentionally oriented so as to simulate the constricted environments in which the startups work, time and money wise. As the course is rigorous 7 week curriculum and time is the biggest constraint the teams are challenged and questioned in the hope

that they will quickly learn. The instructors in the program are very much straightforward, open, and challenging just like the actual world. The Teaching Team is very open and welcome the teams to challenge their viewpoint if anyone disagrees, and engaging in a conversation with the Teaching Team. Overall, the style of the Teaching Team (instructors) may seem to be harsh or severe however their objective is teams challenging themselves quickly and learning faster than ever imagined possible.

Attendance and Participation

It is mandatory for Team members to be present for the kick-off workshop, five online classes, and final workshop. If the teams are anticipating that they might not be able to commit to the course then they should not enroll or apply at a later date to the I Corps Program when they can devote their time to the course.

Class Roadmap

Each class is structured throughout:

1. Talk on each of the 9 building blocks of the Business Model Generation.
2. Teams presenting the “Lessons Learned” from customer discovery process and the process of iteration or pivoting of the business model.
3. The Teams should immediately document the Customer Discovery process on LaunchPad Central (LPC).

Deliverables

1. Recording of the customer discovery progress on LaunchPad Central comprehensively.
2. Every weekly, there would be a 10-minute presentation to the instructing team on the progress of the participating team.

3. Through the Customer Discovery Process the teams would be required to develop a MVP which would help them in communicating the value proposition and product viability with the potential customer.

Pre-class Assignments

1-Minute Technical Video

NSF Teaching Team wanted each participating team to submit a short, technologically driven video which would be appropriate for a technically educated audience.

Some of the important contents included in the technical video to deliver the point of quantum of opportunity in U.S. with regards to landfills is: Figure 12. shows the mapping of the landfills in U.S. with regards to their size and current status. The red dot denotes the landfills which are operational whereas green dot denotes closed landfills. It can be assessed from the figure that the number and size of landfills increases along the heavily populated areas on the east and west coast and southern U.S.



Figure 12: Landfills in U.S. by size and status (EPA, 2018)

Figure 13. shows the different category of LFE energy projects in U.S. The pink dot denotes the projects with electricity generation, green dot for direct use, and yellow dot for RNG/pipeline injection. According to August 2020 data from EPA, there are 399 operational electricity projects, 99 direct use projects, and 58 RNG/pipeline projects in U.S.

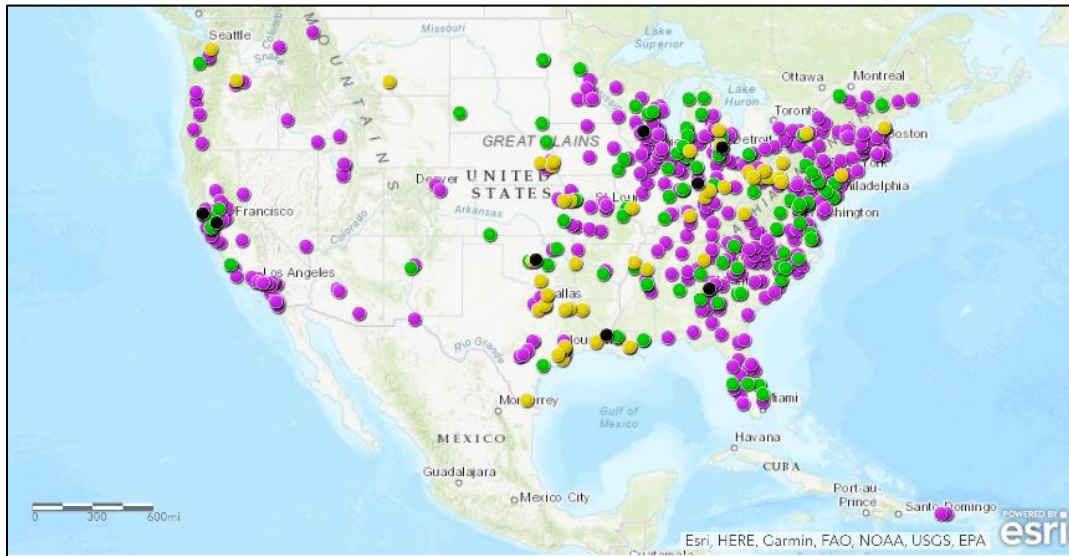


Figure 13: Landfill Gas to Energy Projects in U.S. (EPA, 2018)

The value proposition remained the same as during the participation in ISU I-Corps which is siloxane removal technology for enhancing the life of engine generators and marketable scrap tire rubber particles: efficient and cheaper adsorbent.

As an EL, Sakhalkar included a slide towards the end of the video which shared his vision through the research and participation. First is, approximately 5-7 percent of the daily electricity requirements in U.S. will be met by digester/landfill gas conversion to electricity which would have a potential impact on carbon savings and second is, small medium enterprises (SME's) would benefit through manufacturing opportunities in the form scrap of waste tire rubber particles as an adsorbent media.

Lecture 2: Value Proposition

Table 7. Providing value to customer (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	Value proposition is all about what product services are you building
2.	It includes features of the product as well pains and gains solving for the customer segment
3.	In other words, it is product services we have for product services we are providing
4.	It is about figuring out MVP (minimum viable product)
5.	What product and feature of product is actually a part of your value proposition?
6.	What core services are part of your value proposition?
7.	What problem are you going to reduce or eliminate for your customer?
8.	There should be a clear distinction between solving a problem and addressing a need
9.	Needs are universal
10.	MVP is for testing your understanding of the problem
11.	MVP is for getting customer feedback
12.	MVP is about what products and services you are building in first instance that is delivered to customers
13.	Purpose of MVP is to test the ability to meet minimal customer needs
14.	The art of the MVP is asking the customer, what solutions are you using now?
15.	Value proposition is broadly divided into : technology and market insight

Lecture 3: Customer Segments

Table 8. Knowing customer archetype (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	What is the customer segment you are trying to get done?
2.	To begin with at the initial stage is with series of untested hypothesis
3.	Startup owners should asked themselves, what basic needs are you helping your customers satisfy?
4.	Customer gains should be quantified with effort, money, and time
5.	What solution can delight the customers?
6.	What actions undertaken can increase the likelihood of adopting a solution by the customers?
7.	What problems can startup owners solve for the customers?
8.	What are the main difficulties and challenges for customers?
9.	What causes an issue, concern, or worry for the customer?
10.	What fear does the customer have in adopting a solution?
11.	Have you done in detailed customer profiling?
12.	Customer profiling is extremely important in customer activation

13.	Customer archetypes help us understand customers, value proposition's, revenue, and pricing tactics
14.	Who is the customer in context? Is he influencer, recommender, decision maker, or economic buyer?
15.	Pass/fail experiments can be adopted in knowing the if the customer is the one you need
16.	Market type can be existing, resegmented, new, or clone
17.	Knowing where stand helps startup owner in knowing market (initial market size, cost, launch, competitive barrier, positioning), sales (margins, sales type), finance (ongoing capital) and, customers (needs, adoption)
19.	While jumping in an existing market it is important to look at the innovation rate of the incumbents

Kick off workshop: May 6th (day 1)

On the first day of the program the Teams were asked to present a two slide presentation to the class. The first slide should contain Team Name, Team Number, Product picture/product description, and Pictures/names of Team members. In Figure 14, at the topmost part of the slide the product description was concisely mentioned. The picture of the laboratory set up was referred from that of Dr. Ellis's masters student (Andrea Seifers) who had done in-situ set up for hydrogen sulfide (H₂S) removal using tire derived rubber particles (TDRP) (Seifers, A. 2010).



Figure 14: Slide 1 kickoff Nashville cohort

Slide 2 should contain a populated business model canvas. See Figure 15., BMC was filled up by EL Sakhalkar after discussion with the group members. The one thing that the entire team was sure about was the customer segment of municipal wastewater treatment plants and landfilling enterprises. Value proposition clearly denoted the technology to be developed with reference to siloxanes and the unique removal media (adsorbent) the Team was proposing as a part of the operational process in scrubber column during adsorption. Customer relations would

be maintained on the quality of the consulting offered through the process innovation. Other components of the BMC like revenue streams, channels, key activities, resources and partners, and cost structure was completed with what the team thought was in the best interest with reference to the initial idea.

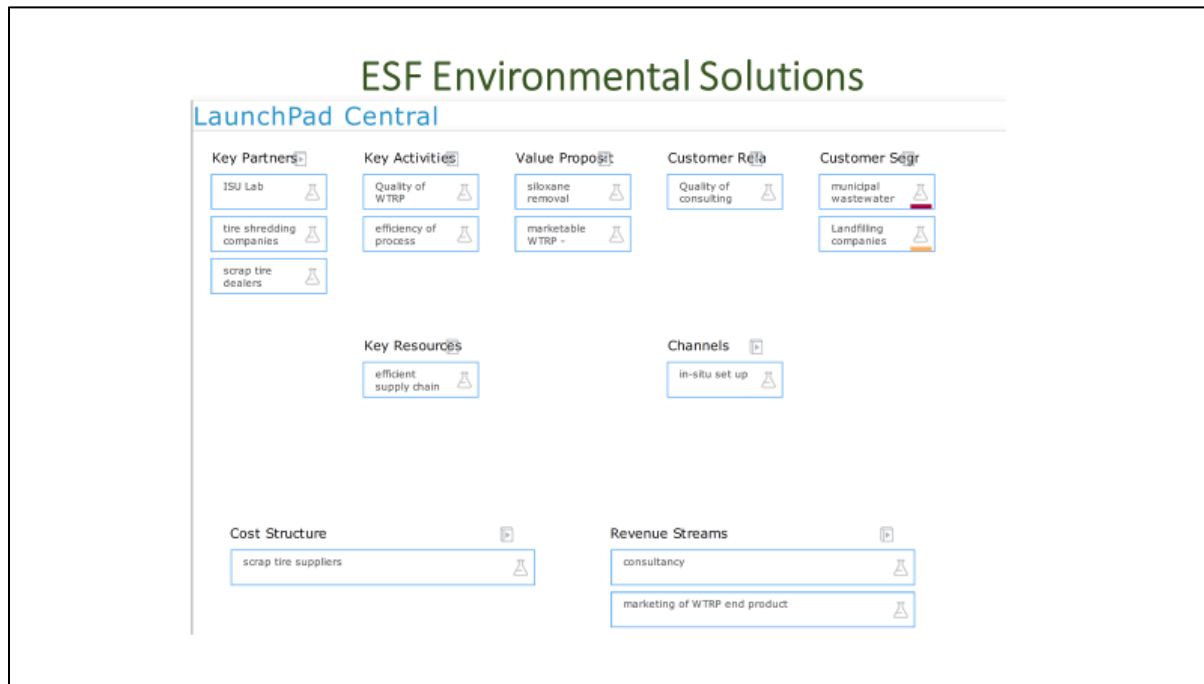


Figure 15: Populated business model canvas

Kick-off workshop : May 7th (day 2)

On the first day of the kick-off, the Teams were asked to step out of the building for customer discovery and document their findings the next day through a PowerPoint presentation. Team Siloxane conducted three over-the-phone interviews on day 1.

The business thesis was updated to: siloxane control in landfill gas and biogas for higher energy output and economic benefits in electricity generation. The business thesis in the first slide was broken down into customer, product, and the reason as to why they will buy the product. The customer was landfilling enterprises, the product was the process of siloxane

control and the reason was economic benefits they would reap from mitigating the damage to different engine components from siloxanes.

The second slide documented the value proposition from talking to the first customers. It had to be documented in the form of hypothesis, experiments, results, and iterate.

- Hypothesis (Here's What We Thought): Siloxane is a nuisance, but to what extent of the 100 percent overall problem faced by generators?
- Experiments (So Here's What We Did): Focused on solely problems faced by power generation industry for landfill gas and biogas.
- Results (So Here's What We Found): Siloxane presence acknowledged. Every state in U.S. has a different priority and approach towards it.
- Iterate (So Here's What We Are Going to Do Next): Focus on specific customer segment based value proposition and discovering.

In the third slide, the different components of customer segments and value proposition were broken down into the designated positions of the customer in question. Customer segments were classified as environmental consultants, engine generator representative, consulting engineer, environmental regulator, landfill owner, landfill operator, anaerobic digester owners, and tire recyclers and processing. The value proposition was further divided into three categories: Siloxane removal technology for efficient electricity generation, marketable WTRP as a cheaper adsorbent, and siloxane removal positively affects the maintenance costs .

In the fourth slide, the teams had to talk about the market size discovered. For Team ESF Environmental Solutions the target available market (TAM) is 2000 active landfills in U.S. The served available market (SAM) is 953 landfills which have operational landfill gas to

energy projects. The TAM for waste water treatment plants is 14728 WWTP's in U.S. of which 300 have active digester gas to electricity projects (EPA-LMOP, 2018).

In the final slide the Teams were asked to mention the future experiments the team would develop to test the customer segment, channel, and revenue. Asking open ended questions about power generation industry, asking bold questions, and being specific in interviewing process such that entire picture is unveiled were the best worked out replies of the team. It was also asked what would constitute to be pass/fail for each test. Team ESF Environmental Solutions was of the opinion that this question can have an answer after 75-80 in-person interviews with landfill and WWTP operators spread evenly across U.S. The thought behind having data from different states is categorizing the replies depending upon the state policies, penetration of solar and wind energy market, electricity rates, and climatic conditions.

Kick off workshop : May 8th (day 3)

Team ESF Environmental Solutions conducted 12 interviews on day 2 of which 1 was in-person and 11 were phone interviews. The total interview count was now 15 of which 14 were phone interviews. Without doubt, it was getting difficult to get in-person interviews considering the level of interest in renewable energy in the State of Tennessee (TN). The phone interviews which were mostly with landfill operators in Pennsylvania gave great insights on the siloxane problem in landfills. Eight landfill operators clearly stated that siloxanes had been rough on the engines and causes scaling on the engine components. One landfill operator was of the opinion that owing to siloxane issue the landfill shifted from cogeneration of electricity to directly selling the gas to end users without pretreatment. One in-person interview with a technical staff member of CDM Smith in Nashville provided interesting details about siloxanes. It was shared with entire team during the interview that scrubber type material (regenerative) can be effective

for removal of siloxanes, however the higher costs incurred poses a serious problem for its adoption. This point was important for the team as it was our initial hypothesis that activated carbon used in scrubber column is an expensive adsorbent. The engineer also shared that engine run time in between rebuilding is generally 8000 hours. However, with siloxanes the time decreases to 7000 hours. Quantification of the data was very important for the team as it provided the values needed to calculate the economic expenses incurred in maintenance due to reduced engine hours.

The value proposition was updated for day 3 which was influenced from the data insights obtained through the interviews.

- Hypothesis (Here's What We Thought): Day 2- Siloxane is a nuisance, but to what extent of the 100 percent overall problem faced by generators?

Day 3 -

1. Siloxane contamination of landfill gas destroys the economic opportunity for small landfill owners to capture value from landfill gas.
 2. Hydrogen sulfide contamination is a bigger problem than siloxane contamination to small landfill owners.
 3. Siloxane is the number one economic challenge for landfill gas to electricity plants.
 4. Increased use of nanomaterials in cosmetics and other personal care products has led to the siloxane problem.
- Experiments (So Here's What We Did): Focused on solely problems faced by power generation industry for landfill gas and biogas (same as day 2).

- Results (So Here's What We Found): Day 2 - Siloxane presence acknowledged. Every state in U.S. has a different priority and approach towards it.

Day 3 –

1. Siloxane was identified as a chief contributor to operating expenses of electricity generation equipment.
- Iterate (So Here's What We Are Going to Do Next): Focus on specific customer segment based value proposition and discovering (same as day 2).

The customer segment remained the same whereas one of the three value propositions mentioned on day 2 was changed. Siloxane removal positively affects the maintenance costs (day 2 -VP) was replaced with siloxane removal decreases equipment maintenance costs (day 3-VP).

Figure 16. shows the updated business canvas. The things Team ESF Environmental Solutions worked out extensively through the interviews are the value proposition and customer segments. It can be seen that in the customer segments section of BMC a role-wise segmentation was done for different components of WWTP's and landfill industry. Our team had taken a confident step towards establishing a clear product-market fit.

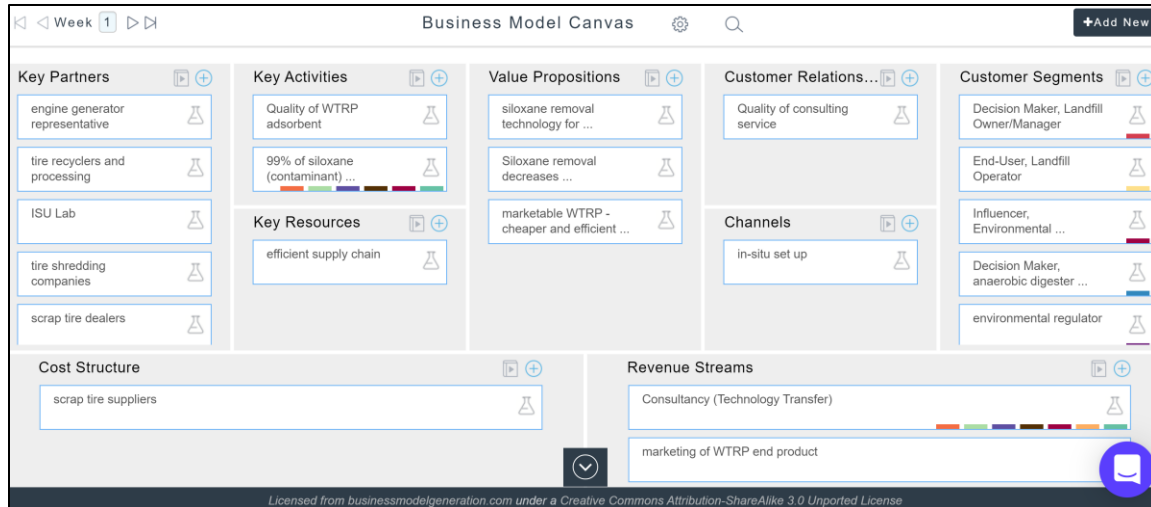


Figure 16: Business Model Canvas week 1 (Launchpad Central)

Online Class 1 (Tuesday, May 14th)

Lecture 4: Distribution Channels

Table 9. Distribution Channels (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	What route does your product take to reach the customer?
2.	Distribution channel can be direct or indirect
3.	Original equipment manufacturer (OEM) is a physical distribution channel
4.	Other physical distribution channels are system integrator, value added/reseller, direct sales force, web/online, dealers, and suppliers
5.	Solution complexity with regards to channels is about increasing complexity of what each channel can actually handle
6.	As the curve of solution complexity goes higher up the more the value added at every step. Higher value comes up with a cost
7.	Product channel fit is as important as product market fit
8.	The purpose of a channel is to have something to focus on in early days of business canvas building

In Figure 17. it can be read that the Team had added 10 new interviews in week 2, of which 7 were in-person, and 3 were phone interviews. The total interview count now stood at 25,

with 11 in-person. The business thesis was updated to: small to medium size landfill owners (customer segment) will buy our siloxane control equipment (process/product) in order to generate net positive cash flow from onsite electrical generation (value proposition - addressing customer need).

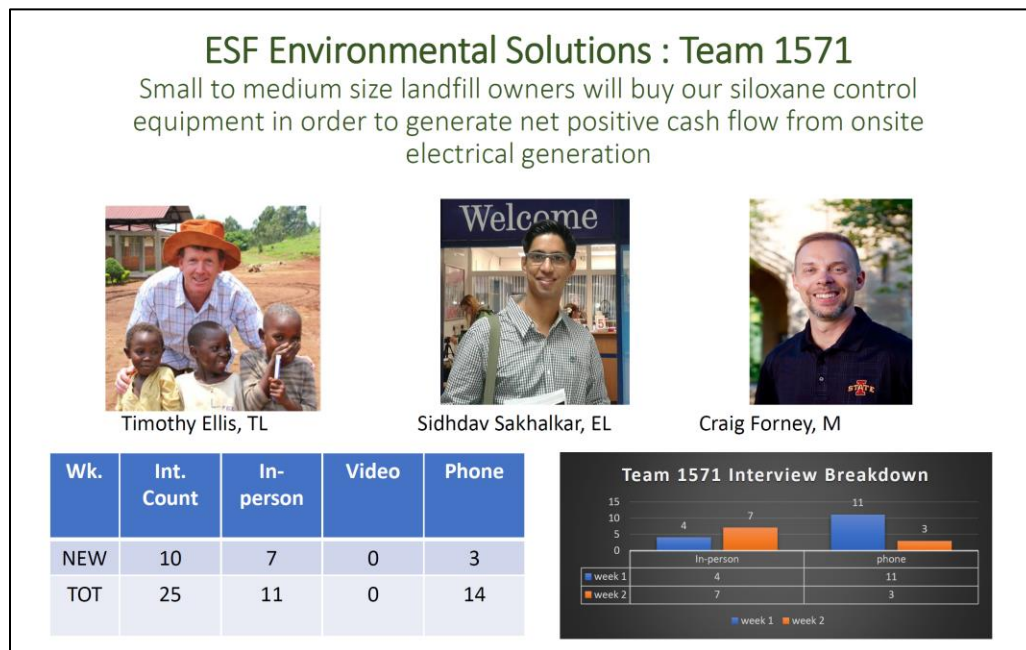


Figure 17: Title slide with business thesis

It can be seen in Figure 18. that value proposition was refined by the process of proposing a hypothesis, experiment, results, and iterate. The testing of the hypothesis was quite successful with customers acknowledging that there is siloxane problem. However, much work needs to be done with iteration especially understanding the extent of damage caused by siloxanes to engines and the economics involved.

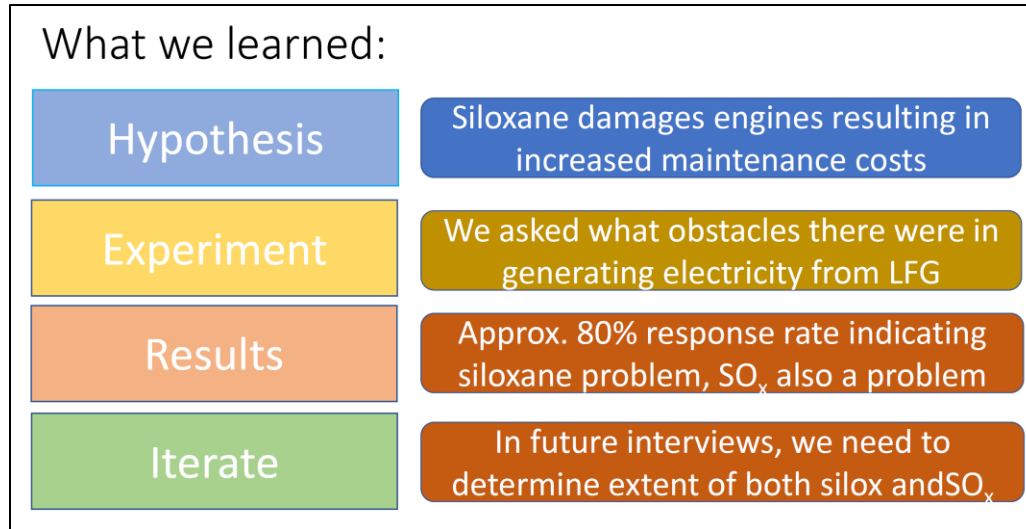


Figure 18: Value Proposition (damage to engines)

Figure 19. shows the way in which hypothesis that siloxane is an economic challenge for landfill operators was tested through the interviews. The results were very much positive with validations from the customer segment concerning an increase in production costs and decrease in electricity output. Further iterations can provide the savings in maintenance costs per kWh generated.

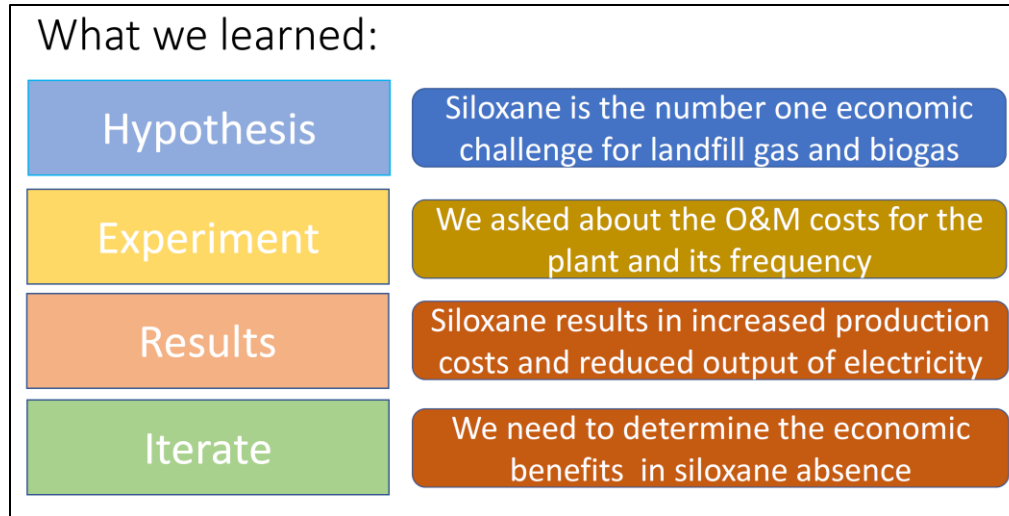


Figure 19: Value proposition (economic challenge)

Figure 20. shows clear distinction between WWTP's and landfills depending upon the role of each designated position. This would help the teams not only during the customer discovery process but also would benefit beyond the product market fit in customer activation process which is the after stage of customer validation. The interesting thing our team discovered through customer diagram is within a particular category e.g., WWTP there is different insights learnt from the people within the organization/enterprise depending upon their roles.

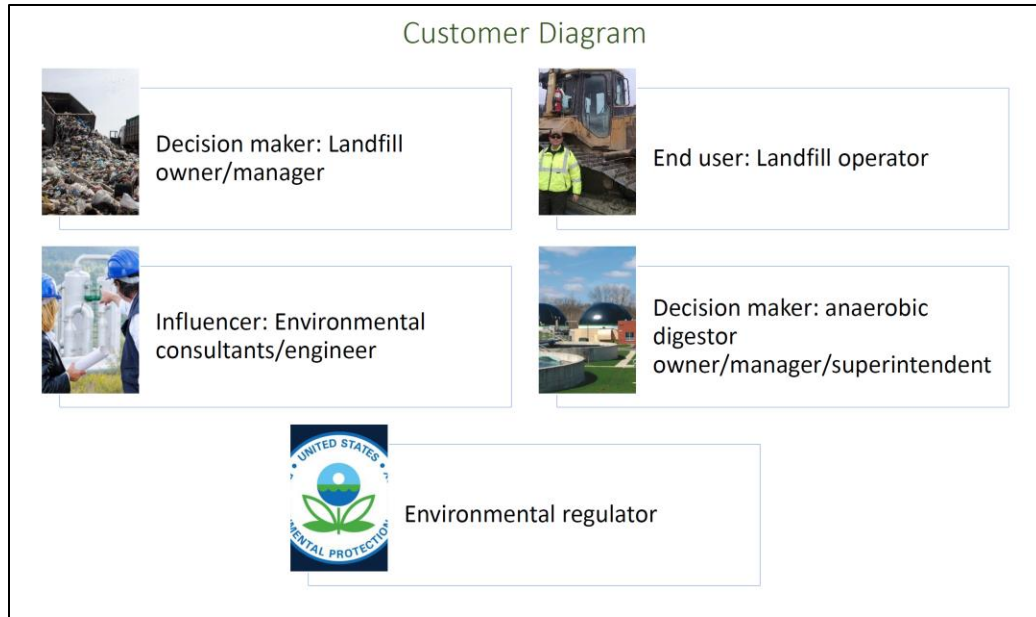


Figure 20: Customer segment archetypes

Petal diagram (see Figure 21.) shows the intersection between our solution to solving the siloxane problem and other solutions. For our Team it aided in understanding who the existing competitors are, what technological substitutes are being used currently, and the way in which the problem is being addressed at present.

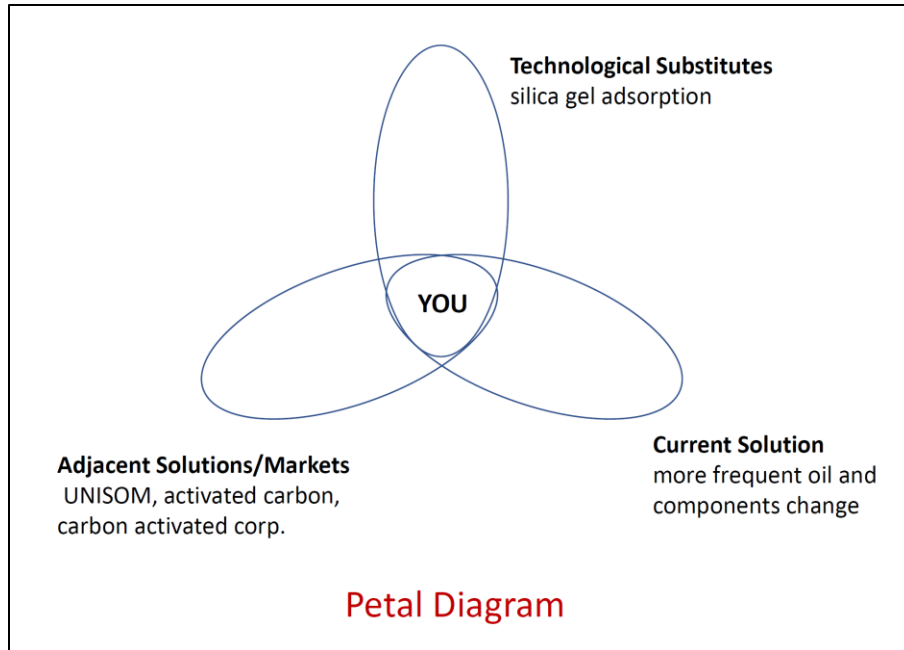


Figure 21: Petal Diagram (ESF Environmental Solutions)

Figure 22. shows the updated business model canvas for week 2. The value proposition was updated from week 1. The consulting engineer as a customer segment was removed as shown in Figure 23. The value proposition of siloxane removal technology for efficient landfill gas and biogas generation matches with all the five customer segments. The purpose of having multiple value propositions is what our Team was realizing that we could focus towards the end on 1-2 VP's which matches almost every customer need.

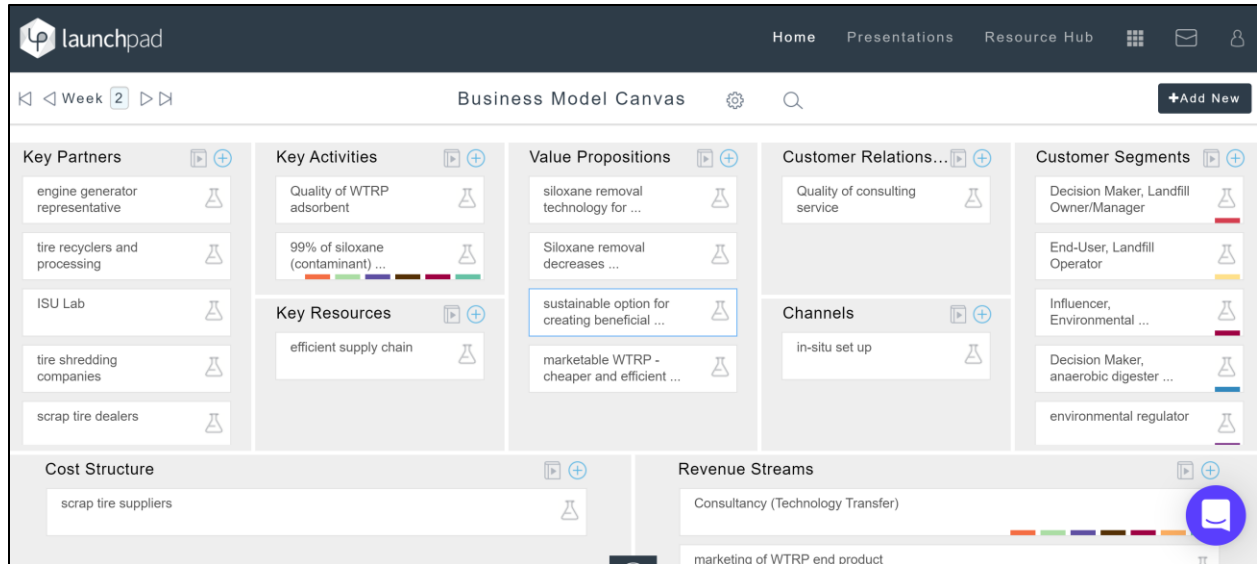


Figure 22: BMC week 2

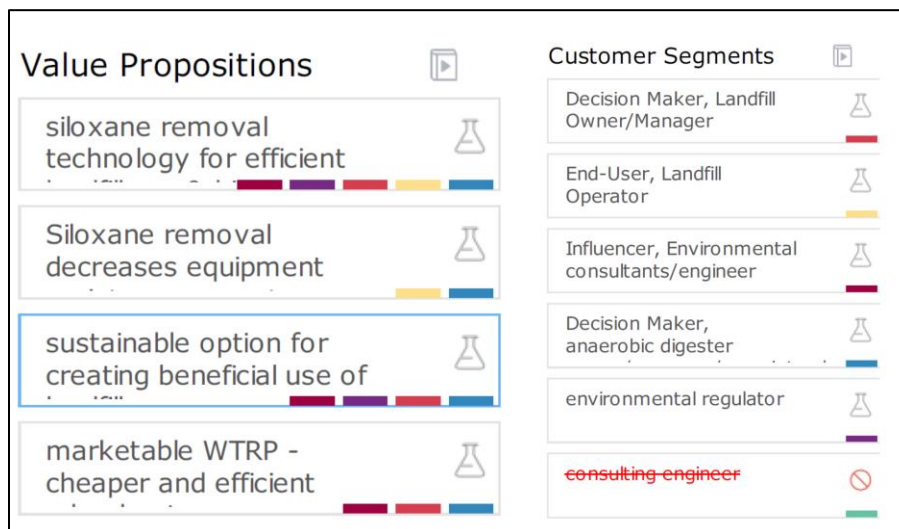


Figure 23: Value proposition and customer segments (week 2)

Online Class 2 (Tuesday, May 21st)**Lecture 5: Customer Relationships**

Table 10. Customer relationships (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	Customer relationships is made up of - get, keep and, grow
2.	Customer archetypes drives get-keep-grow
3.	The inputs which we put in the funnel of get-keep-grow is called as demand creation activities
4.	It is cheaper to sell existing customers the product than to get new customers
5.	Customer acquisition cost (CAC) should always be known for the business owner
6.	The factors needed for calculating CAC is – customers acquired, activation percentage and price per customer
7.	We can get more revenue from existing customers by just working on getting to keep these customers around
8.	Life time value (LTV) needs to be greater than customer acquisition cost (CAC)
9.	Life time value (LTV) is the customer life time value from beginning to the end

In Figure 24. it can be read that the Team had added 17 new interviews in week 3 of which 10 were in-person, 3 were video, and 4 were phone interviews. The total interview count now stood at 42, with 21 in-person. The business thesis was kept the same as before which is: small to medium size landfill owners (customer segment) will buy our siloxane control equipment (process/product) in order to generate net positive cash flow from onsite electrical generation (value proposition - addressing customer need).



Figure 24: Title slide with business thesis

To make the teams understand the concept of channels through direct sales we had to show a slide with an example of the same. Figure 25. shows the listed price of technology as \$5000. Considering discount of 20 percent it comes to \$4000. The various costs incurred by the team in R&D, sales, general, and administrative costs is fixed at \$1000. The profits incurred is \$3000.

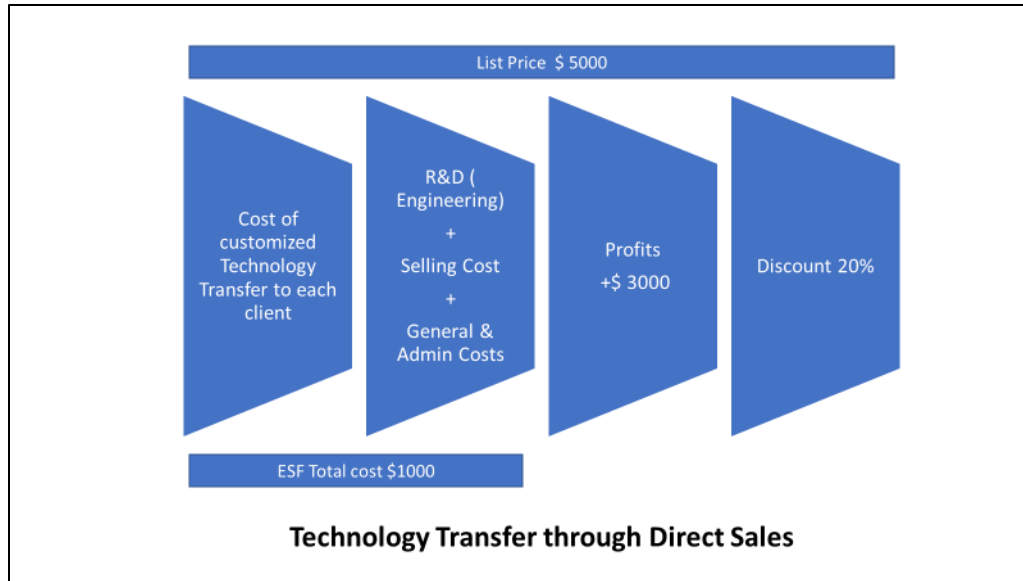


Figure 25: Direct sales cost breakup

Figure 26. shows the distribution complexity of technology/process and WTRP (adsorbent media) through direct sales. As the curve is going higher more value is added at every each step. The graph shows solution complexity versus marketing complexity.

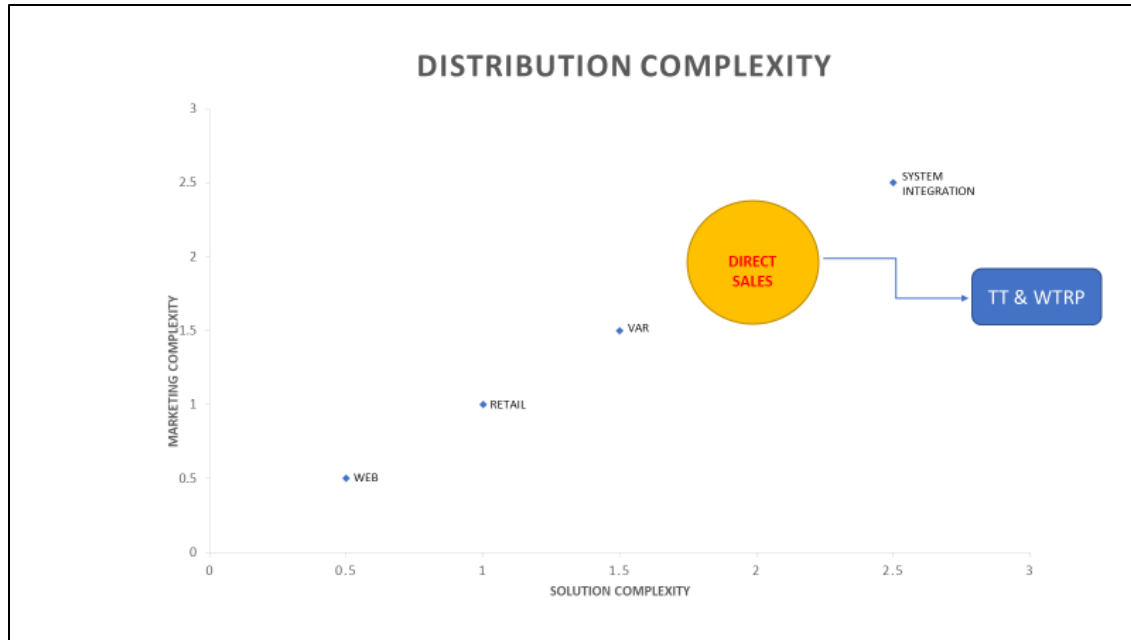


Figure 26: Distribution complexity

In week 3 our Team checked the hypothesis if direct sales is the one that is product-channel fit for our proof of idea (see Figure 27). It was fairly evident from the responses that direct sales is the most ideal path for the product/technology to reach the customer. Since channels are an extremely important component of the business canvas which involves direct coordination between the customer and business owner, a considerable number of iterations over different hierarchies of customers would be needed to validate the hypothesis.

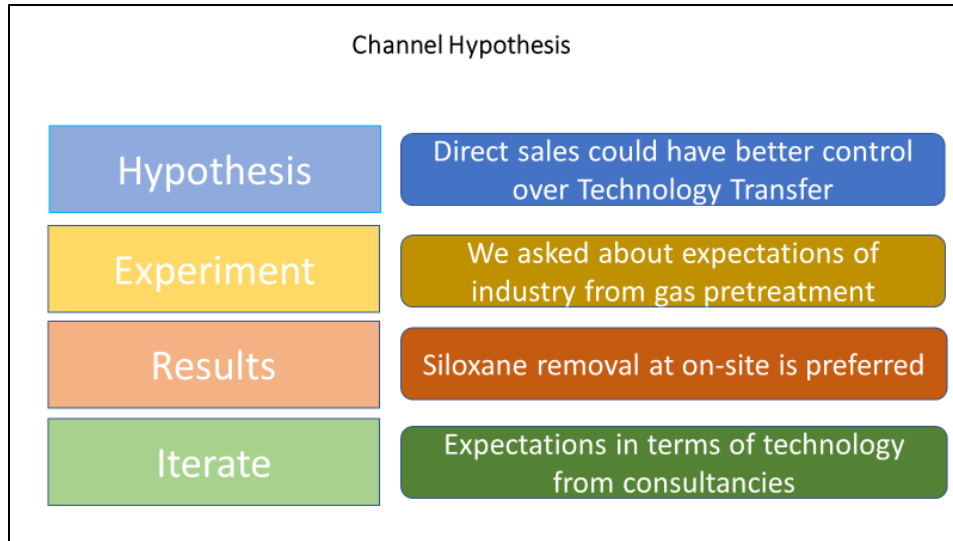


Figure 27: Channel hypothesis

Business Model Canvas in week 3 was focused upon the synchronization between customer relationships and customer segments. Our team came to the consensus that efficiency of technology transfer and removal efficiency of WTRP adsorbent will fit with decision maker and influencer for the customer segment. In Figure 28. with channels component of business canvas, it can be seen that direct sales is related to decision maker of landfills and WWTP's customer segment.

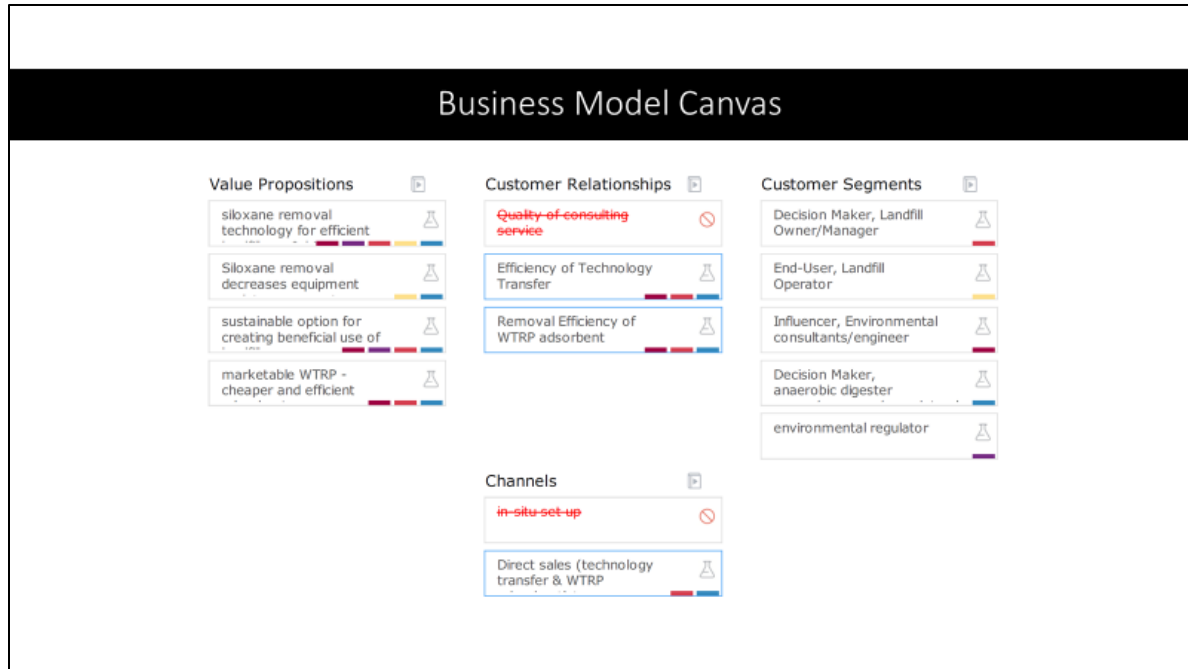


Figure 28: Business Canvas week 3

Online Class 3 (Tuesday, May 28th)**Lecture 6: Revenue Model**

Table 11. Value to the customer (Revenue Model) (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	Revenue model is different from pricing
2.	Revenue streams is the strategy of a company use to generate cash from each customer segment
3.	What value is the customers willing to pay for?
4.	How do the customers pay today
5.	How much do the customers pay today
6.	Each revenue stream may adopt different pricing tactics
7.	Fixed pricing is classified into - fixed price = cost + profit (mark-up) which is equal to minimum price in market, pricing based on customer segment (value pricing), and volume pricing (step pricing which is oriented to create volume)
8.	Dynamic pricing is classified into - negotiable pricing, yield management, real time markets, and auctions
9.	Costing should be driven by internal economics and not customer insight and based on value
10.	Pricing should be done as a strategy and not a reaction

11.	Single sided markets care about revenues
12.	Multi sided markets care about users first, revenues second

From Figure 29. it can be deduced that the Team added 18 new interviews in week 4 of which 15 were in-person and 3 were phone interviews. The total interview count now stood at 60, with 36 in-person.



Figure 29: Title slide week 4

After brainstorming as a team and meetings with the group instructor - Christina Pellicane, we had a more focused and customer centric value proposition. Siloxane removal technology for efficient landfill gas and biogas generation was changed to: Increasing operator revenue (customer) up 3 percent (value added) by decreasing IC engine maintenance (cost savings). Siloxane removal decreases equipment maintenance costs was changed to: Increasing efficiency of electricity generation by 2 percent (quantifying the value through increased energy output).

Our team believed we needed a more customer oriented and appealing business thesis. The old thesis of ‘small to medium size landfill owners will buy our siloxane control equipment in order to generate net positive cash flow from onsite electrical generation’ was updated to: Landfill owners accepting 220 tons or more of waste per day will buy our siloxane control equipment in order to generate net positive cash flow from onsite electricity generation and better access to RIN (Renewable Identification Number) markets. The interviews we had in week 4 had provided sufficient evidence to our team that RIN credits is driving the digester/landfill gas market to generate renewable natural gas and selling it to the natural gas suppliers to avail the value as well the credits. Knowing that RIN credits is the driving force gave much momentum to our Team in the further weeks to ask much focused questions related to RNG.

There was a significant change in our Team’s ecosystem diagram as well (see Figure 30). In end user: wastewater treatment plant operator was an addition, in Influencer: mechanical specialist was an addition. EPA came into question as it is the federal branch through which RIN credits are administered.



Figure 30: Updated customer ecosystem

The team also had to focus on knowing the market size so as to understand the magnitude of the opportunity. After brief research involving the existing opportunities with biogas, the untapped (unexplored) potential of digester/biogas in U.S. and also taking into consideration policies of different states for renewables (solar/wind) - EL Sakhalkar calculated the approximate value of total available market as \$122.25 million, served available market as \$36.675 million and target market (ESF Environmental Solutions) as \$1.834 million (see Figure 31).

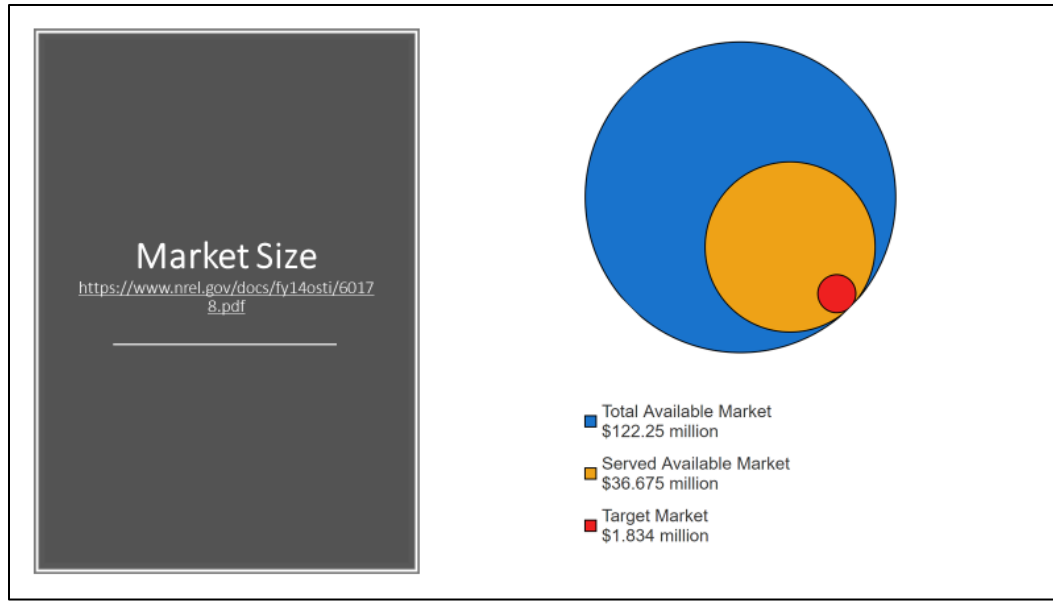


Figure31: What's your slice?

Customer relationships are dependent on the get-keep-grow process. The funnel diagram (see Figure 32.) shows the different stages involved in it. Existing customers can generate more revenues by referrals, up-selling, up-building, and cross selling than spending on acquiring a new customer. The life time value (LTV) as shown in the figure which starts when the customer makes the first purchase should always be greater than customer acquisition cost (CAC).

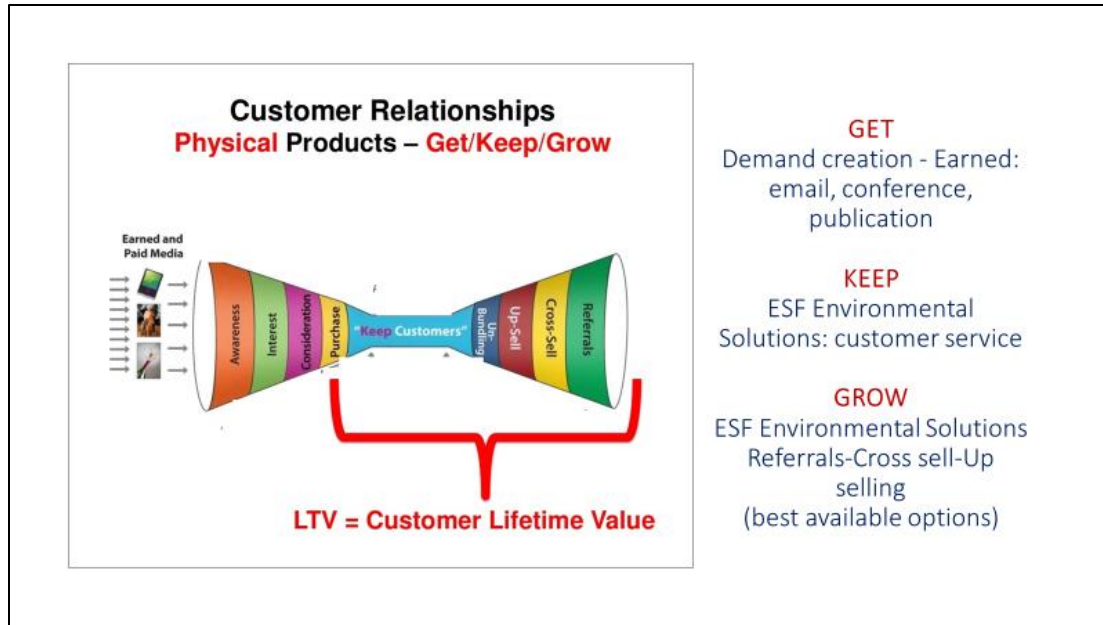


Figure 32: Maintaining customer relationships

Figure 33. paid demand creation and Figure 34. earned demand creation was an attempt by our Team in assessing the technique in which we can acquire customers in the future. TL Ellis and EL Sakhalkar had previously attended the WEFTEC conference in October 2018 in New Orleans, LA and in September 2019 at Chicago, IL. WEFTEC conference which is the biggest wastewater/water conference in the world attracts a large number of companies from over 128 countries.



Figure 33: Paid demand creation



Figure 34: Earned demand creation

The Teams in the cohort were asked to make a budget forecast with what solution they want to achieve and their actual expectations. ESF Environmental Solutions wanted

commercialization of their pre-treatment technology for digester/landfill gas to improve the economics of the WWTP and landfill operation. The Team's expectation was that landfill owners who accept more than 200 tons of waste per day should purchase our siloxane control equipment and technology.

The hypothesis of the presence of contaminants in digester/landfill gas and the effect it has on maintenance of engine generators gave our team during interviews data of different strategies adopted by the operators in temporary mitigation of the problem. These were the things which were employed by the operators or the plant owners without actually eliminating the root of the problem with siloxanes. (See Figure 35.) in the results that changing filter every 750 hours or changing oil every 1500 hours were some of the temporary solutions.

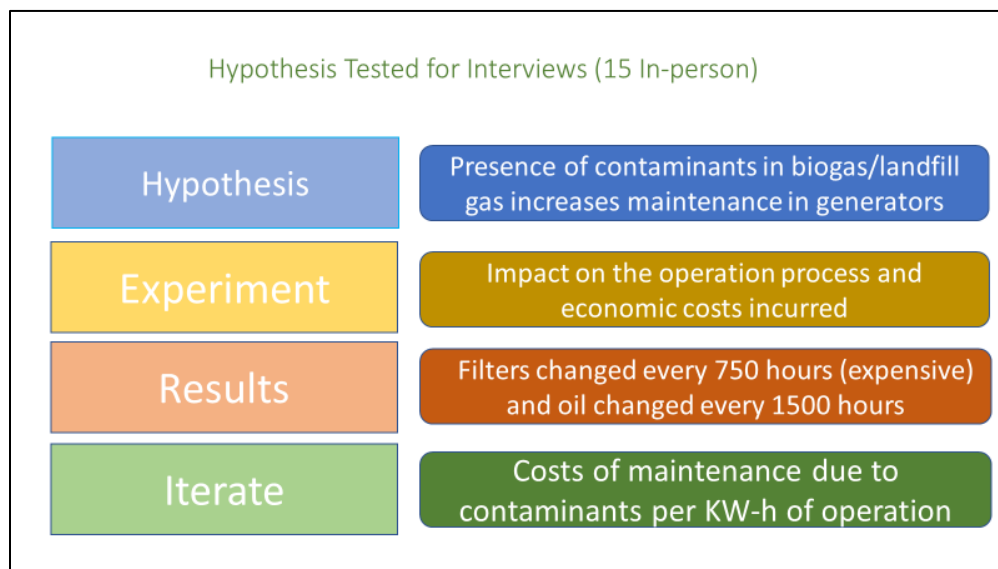


Figure 35: Alternative mitigation remedies (hypothesis testing)

As mentioned earlier, the only significant change in BMC was having two new updated value propositions and eliminating the four value propositions from week 3. In Figure 36. it can be seen that the two updated value propositions match all the five customer segments.

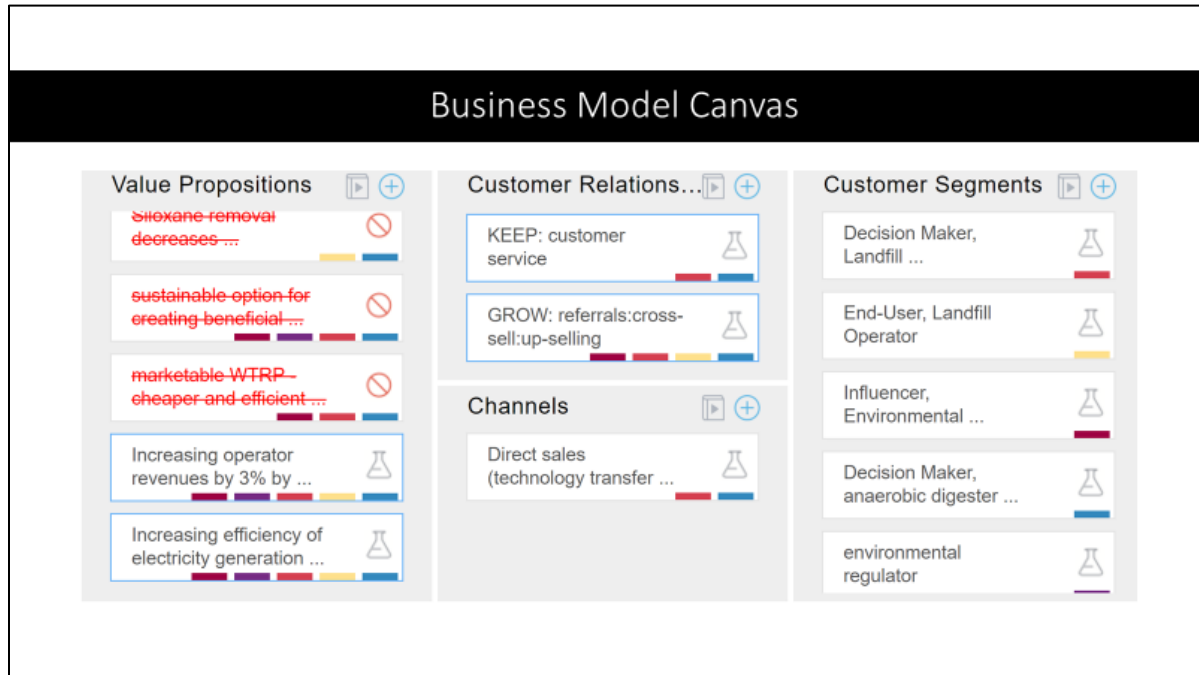


Figure 36: Business Model Canvas week 4

Online Class 4 (Tuesday, June 4th)**Lecture 7: Partners**

Table 12. Who can be your partner (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	What type of relationships do you want with your partner?
2.	Reasons to partner can be - shared economics, economies of scale, money and resources, access to customers, and access to marketing/brand
3.	Partnerships are not add on's
4.	Partnerships help a start up to capitalize on unique customer knowledge or expertise
5.	Partnerships are never driven through spreadsheets, they are driven by technical expertise, customer demands, and capability to deliver a final completed technical product
6.	While managing partners risks the things to be taken into consideration include - impedance mismatch, in joint venture (JV) there is no clear ownership of customer, products lack vision (shared product design), different underlying objectives in relationship, churn in partner's strategy or personnel, IP issues and difficult to unwind or end

7.	Taking an investment from a large company depends upon who is the sponsor and what is the motivation?
8.	Finding the partners who gives a startup owner an unfair advantage is important

Figure 37. which is the title slide of class 4 shows that the Team added 18 new interviews in week 4 of which 16 were in-person, and 2 were phone interviews. The total interview count now stood at 75 of which 52 were in-person, 3 were video, and 20 were phone interviews. The business thesis was the same as in week 4.



Figure 37: Title slide week 5

As the interviews were progressing and more customer discovery was adding to data insights, the motivation behind RNG was clear to the team. RIN credits were revolutionizing the RNG market. In Figure 38. it can be seen that landfill operator: cogeneration, WWTP operator: RNG, WWTP operator: boiler, and developers: RNG were new additions to the existing customer ecosystem. The three customer branches now existed for the Team: cogeneration, boilers, and RNG.



Figure 38: Updated customer ecosystem

Considering the changing scenario of the digester/landfill gas market and the upcoming opportunities through construction of new wastewater treatment plants utilizing electricity, WWTP's setting up anaerobic digestors, new and existing landfill opting for cogeneration and existing digester/landfill gas projects switching from cogeneration, and boiler to RNG - EL Sakhalkar recalculated the approximate total available market to be \$1.342 billion and target market to be \$201.361 million (see Figure 39).

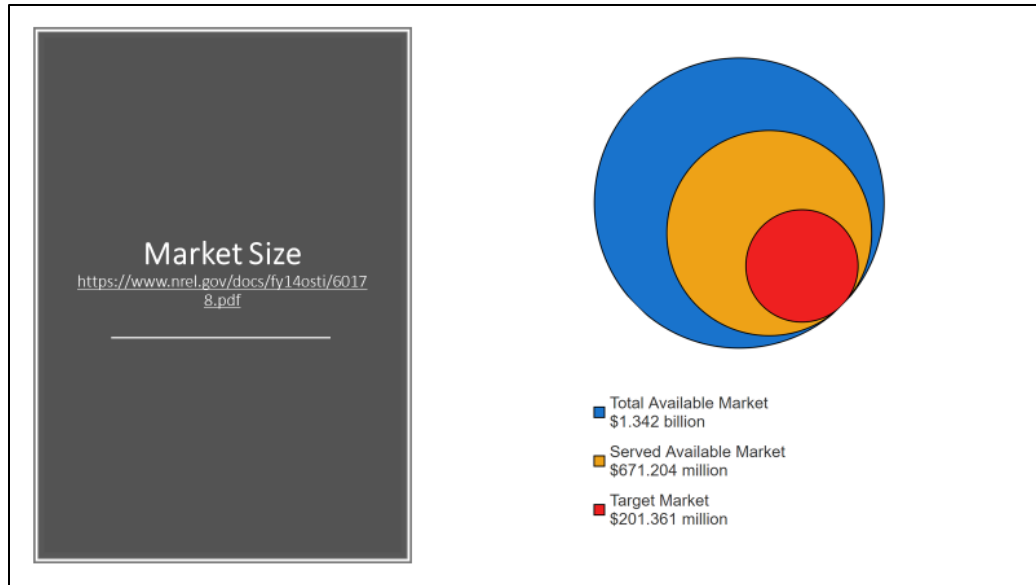


Figure 39: What's your slice ? week 5

In Figure 40. of hypothesis testing of the presence of contaminants from week 4, the experiment question was changed to asking of obstacles in engine generators for electricity generation. On a surprising note, the results were the same as in week 4.

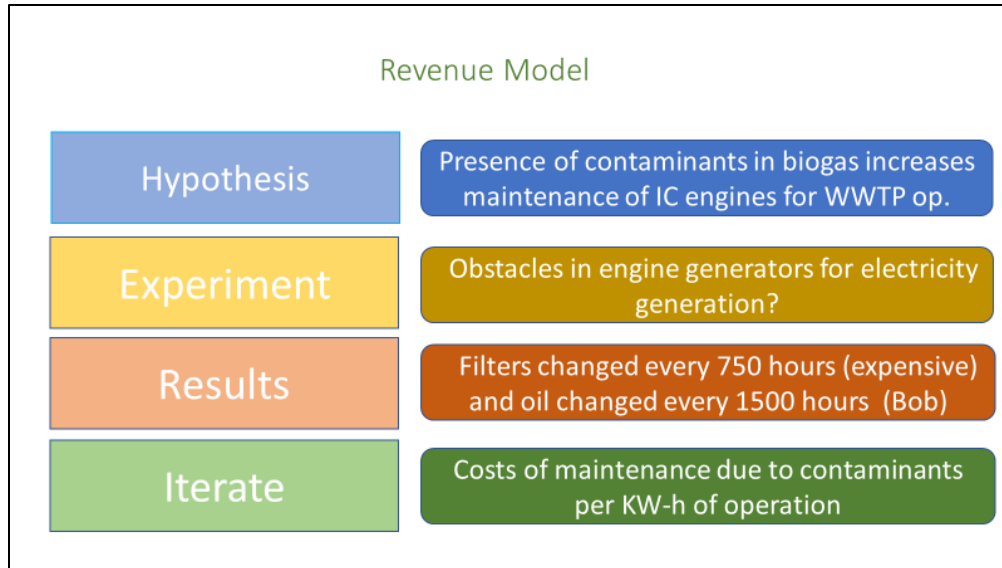


Figure 40: Hypothesis testing updated from week 4

Figure 41. is a rough preliminary estimate of the correlation between the product/service provider (ESF Environmental Solutions) and three different customer segments of WWTP operator: co-generation, consulting engineers (environmental consultants), and WWTP operator: RNG. The figure shows the payment flow pattern between ESF Environmental Solutions with each customer segment.

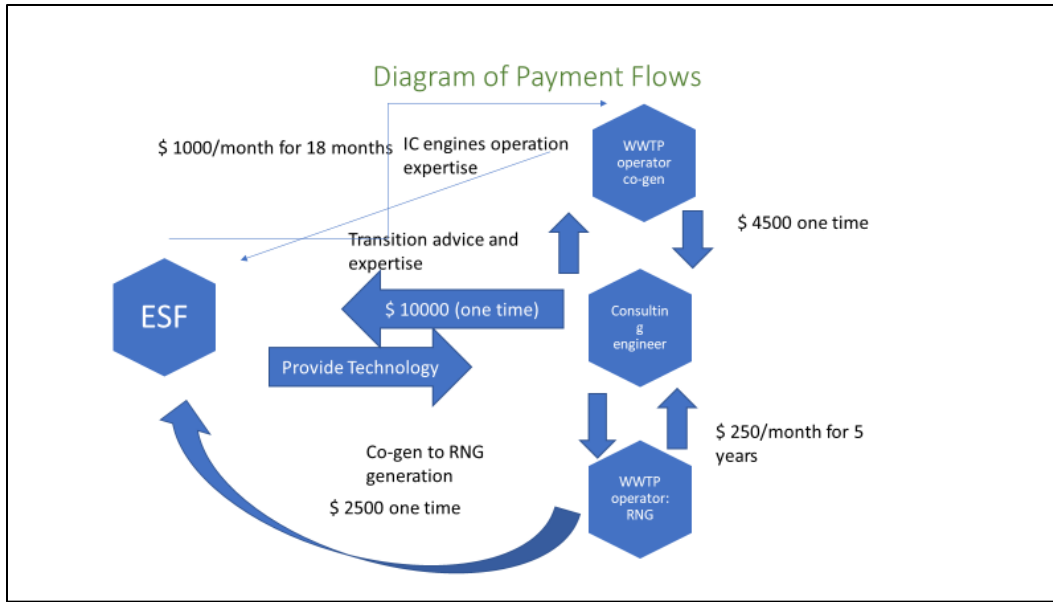


Figure 41. Payment flows rough estimate

The value proposition in week 5 was updated. As compared to week 4 when there were two value propositions there were 12 value propositions now. The value propositions most compatible with customer segments from Figure 42. is the stewardship of public funds, and environmental responsibility.

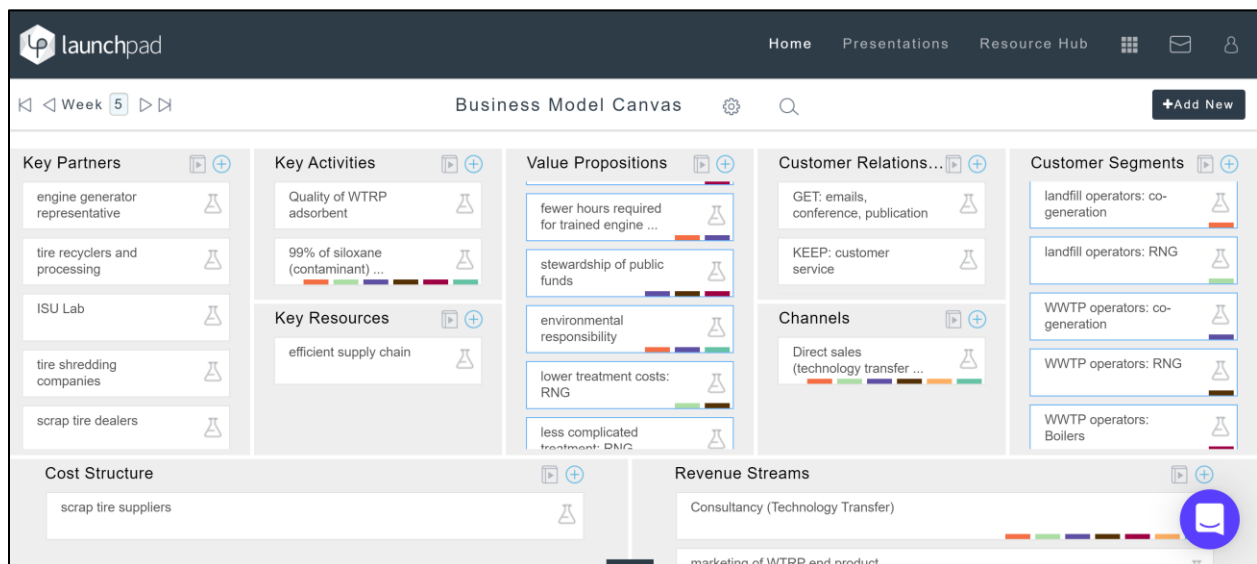


Figure 42. Updated BMC week 5

Figure 43. shows the lifecycle of RIN. RINs are the currency of the RFS (Renewable Fuel Standards) and used by the obligated parties (refiners or importers of gasoline or diesel fuel) as a compliance mechanism so as to meet the annual RVO (Renewable Volume Obligation) directive (Pleima, 2019). The figure shows that the renewable fuel has RINs attached to it. Once this fuel proceeds to a blender then the blender can blend it with nonrenewable fuel and the blended fuel can proceed to the service station. The blender can separate the RINs and sell it in the market depending upon the category of the fuel. Purchased RINs are retired to fulfill RVO.

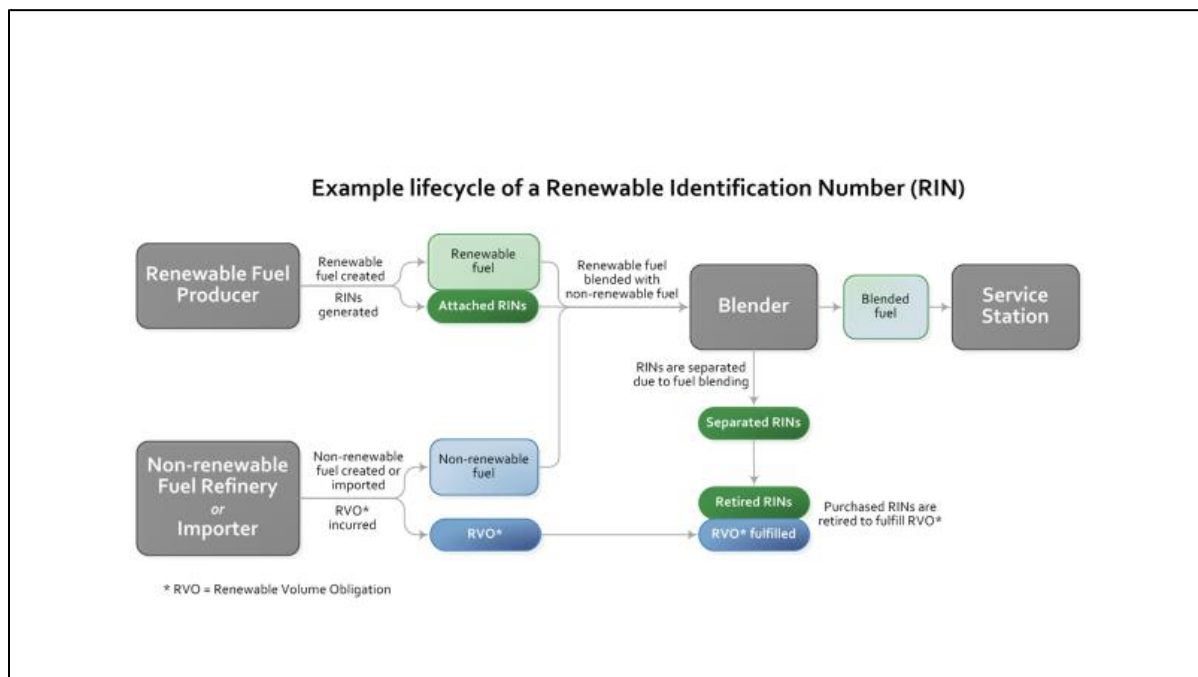


Figure 43: Lifecycle of RIN (EPA, 2017)

Online Class 5 (Tuesday, June 11th)**Lecture 8: Resources, Activities & Costs**

Table 13. Resources, Activities & Costs (Blank, S. LaunchPad Central, Inc.)

Sr. No.	Things learnt
1.	What resources would be needed to make business model work?
2.	Resources are - physical (company facilities, products/services), financial (friends, family, crowd funding, angel), intellectual, and human
3.	IT helps to precompute the capital which might be needed (venture capital, corporate, partners, SBIR/STTR grants, SBA grants)
4.	Founders fail when they believe there is a fact
5.	Listening to experienced advice can help you sort out whether your vision is a hallucination
6.	Having an advisory board is very important that it's an explicit step in customer development process
7.	Copyright protects creative work of authorship
8.	Patent is a government granted monopoly
9.	Costs need to be less than revenue stream
10.	Costs can be fixed or variable
11.	Metric that matter are value proposition, revenue stream, operation cost, market type/ burn rate, customer relationships, channel

Figure 44, which is the title slide of class 5 shows that the Team added 22 new interviews in week 5 of which all were in-person. The total interview count now stood at 75 of which 52 were in-person, 3 were video, and 20 were phone interviews. The business thesis was the same as in week 4.



Figure 44. Title slide week 6

The business thesis of week 5 was further updated: Landfill owners accepting 220 tons or more of waste per day will buy our siloxane control equipment in order to generate net positive cash flow from onsite electricity generation and better access to RIN (Renewable Identification Number) markets. Later this was changed to: Landfill owners generating 200 SCFM or more will buy our siloxane control equipment in order to decrease engine/microturbine maintenance cost by 5 percent from onsite electricity generation. After 6 weeks of repeatedly changing the business thesis our team had created the most compatible thesis to fit into the customer segments.

Figure 45. shows the correlation and dependence between different customer segments.

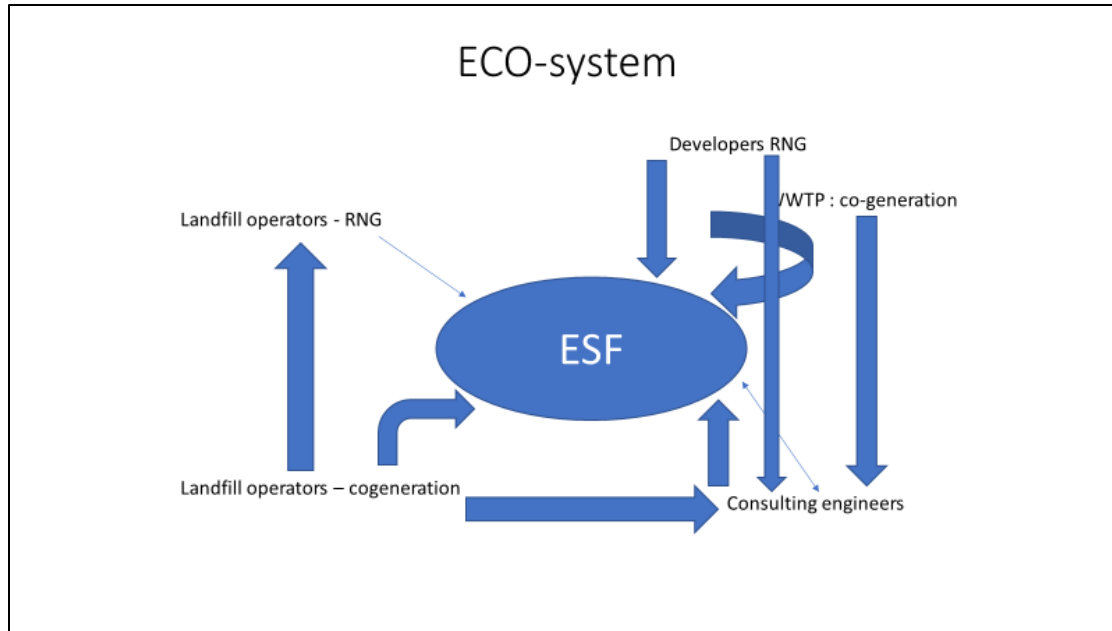


Figure 45: Correlation between customer segments

Figure 46. shows the hypothesis testing by Team ESF Environmental Solutions for shared economics. In the case of ESF and HDR both share a common goal of addressing the customer need of increasing the operational time of IC engines. Results show that one of HDR's client spends \$50k on engine parts every 10,000 hours of operation.

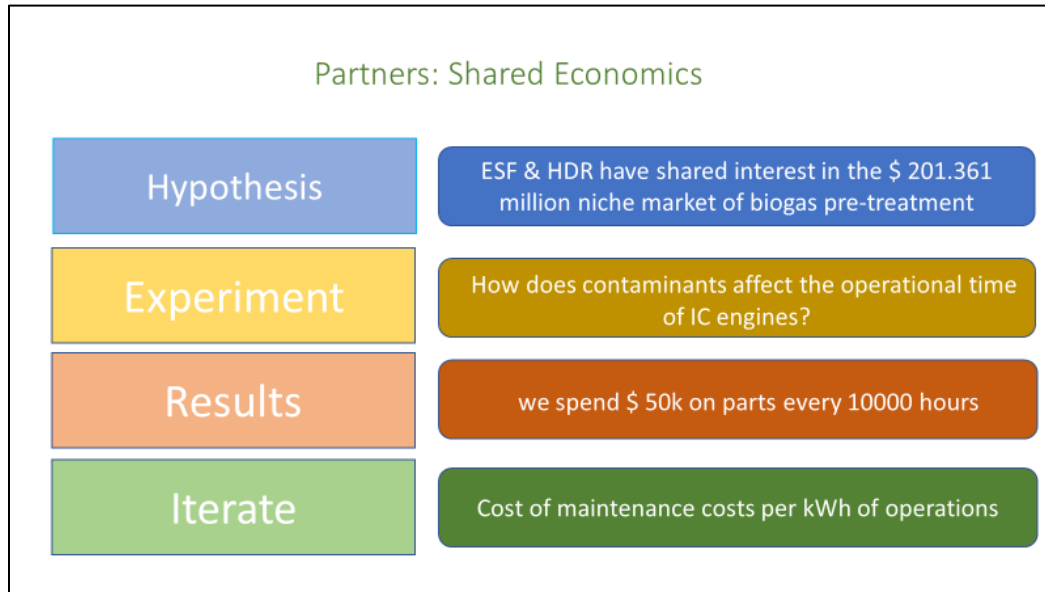


Figure 46: Hypothesis testing (shared economics)

Figure 47. shows the hypothesis testing for benefiting from economies of scale. HDR and CDM Smith are large environmental consulting companies in the U.S. Their supply chain, contacts, and marketing can benefit ESF Environmental Solutions.

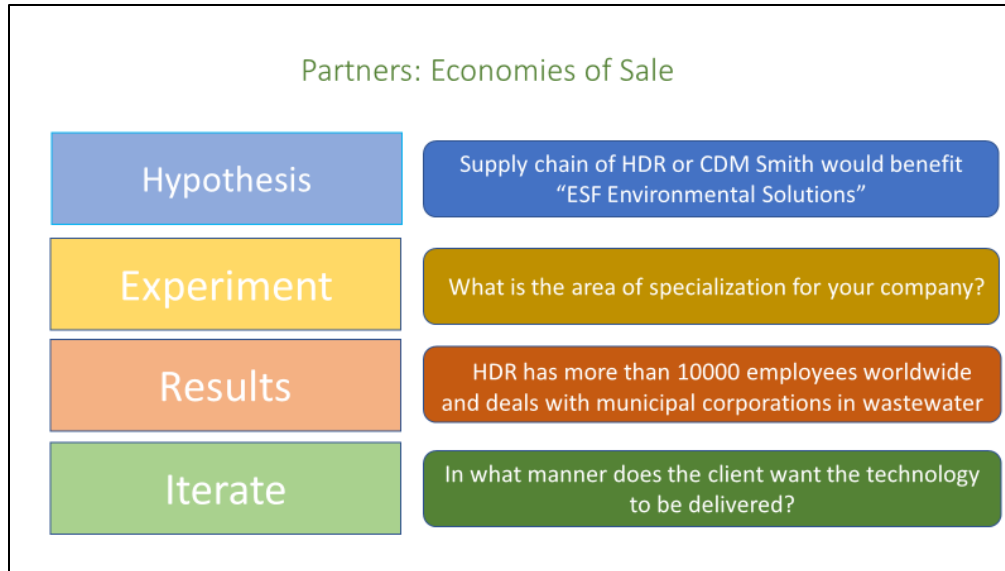


Figure 47: Hypothesis testing (economies of scale)

Figure 48. hypothesis testing shows how strategic alliances can work between two unknown partners. Environmental consultants have clients from different customer segments. These clients approach consultants for sharing their range of problems with respect to energy production. These clients also want consultancy with RNG and/or co-generation. HDR or CDM Smith can direct the clients to ESF or get into a strategic alliance.



Figure 48. Hypothesis testing (strategic alliances)

Lessons Learned Video: June 18th (2 minute – Lessons learned video)

Three days prior to our closing workshop on 21st June the participating teams had to upload a lessons learned video.

What led to our energized perspective in the seven weeks duration?

After 110 pool of interviews over 15 U.S. states, five WebEx sessions, two group meetings with the team, and four skype meetings with NSF instructors, our perspective had totally changed in 7 weeks. Seven week process of rigorous customer discovery helped us reinforce the thought that precursor to developing an innovation is understanding the pain points faced by the industry.

What did we present in our video?

A valuable insight from the interviews was that the “payback period” is what the industry and investors consider for investing in digester/landfill gas and electricity projects. The technology is the result of the research steps undertaken to achieve this objective. Decreased

engine maintenance costs became our main value proposition. In the process of interviews, our team learned that RIN credits through U.S. - EPA is the driving force behind the renewed interest in generating energy from digester/landfill gas in U.S. Generating renewable natural gas (RNG) for pipeline injection is what the industry is focused on.

Figure 49. shows the summarized priorities starting from left (very important) to right (less important) for the customer segments interviewed over the 7 weeks duration. Payback period and RIN market was found to be the primary driving factors for pre-treatment of digester/landfill gas for removal of siloxanes. Other factors including electricity prices, renewable energy sources, and distance of site from the grid were acknowledged as a concern by some interviewees. It was however, reiterated that these factors would not influence the decision making process for technology adoption.

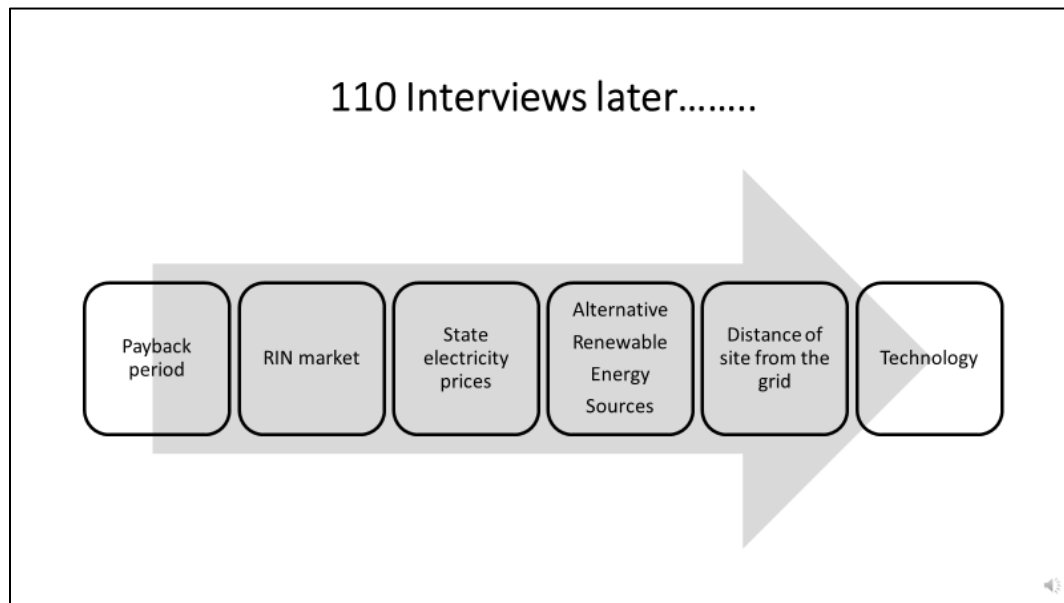


Figure 49. Priorities of customer segments

Figure 50. is the summary of the two most important parameters which can result in customer segments opting for biogas pretreatment for cogeneration, boilers, or RNG.

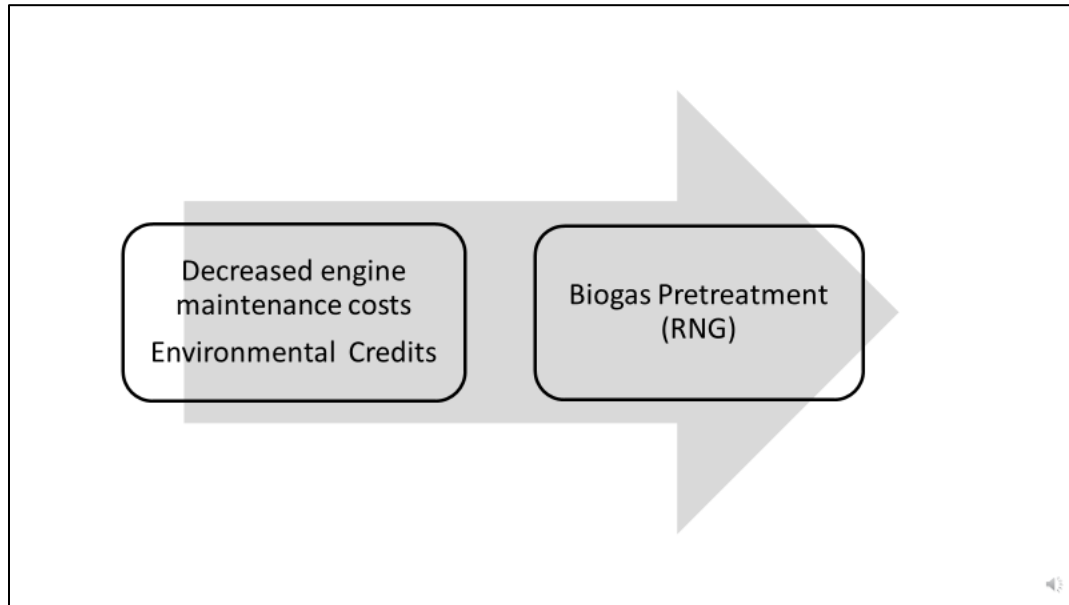


Figure 50: Motivation for biogas pretreatment

Final Presentation - Lessons Learnt : closing day (21st June)

On the closing day of NSF Innovation Corps program the teams had to present a 10 minute lessons learned presentation, the objective of which is to tell the story of your customer discovery journey. Our team shared a common vision at the end of our NSF Innovation Corps journey that, “ our research becomes the cornerstone for 1200 digester facilities and 2000 active landfills in U.S. to generate clean electricity. The interviews were conducted over a diversified range of people from the wastewater and landfill industry, who shared with us the actual pictures and personal experience of the damage to engines and other components due to lack of pretreatment of biogas. Our group had come a long way through the customer discovery journey. We had 110 first hand interviews which clearly simplified the requirements of the market. Our

group also had previous laboratory results which clearly showed the effectiveness of waste tire rubber particles being an effective adsorbent for collection of siloxanes in a scrubber. However, in spite of all of this our group decided not to proceed with immediate commercialization as we had some unanswered questions which could only be realized with continued customer discovery and developing a prototype. The questions are as follows: how do customers interact with marketplace, how much of the value can we expect to realize, what is the cost to our solution, how do we work with our partners to have system recommended, and how do we better understand revenue models. It was our conviction that with PFI-TT funding we could de risk our technology prior to commercialization.

Figure 51. shows the breakdown of 110 customer discovery interviews of which 87 were in-person, three were video, and 20 were phone interviews.

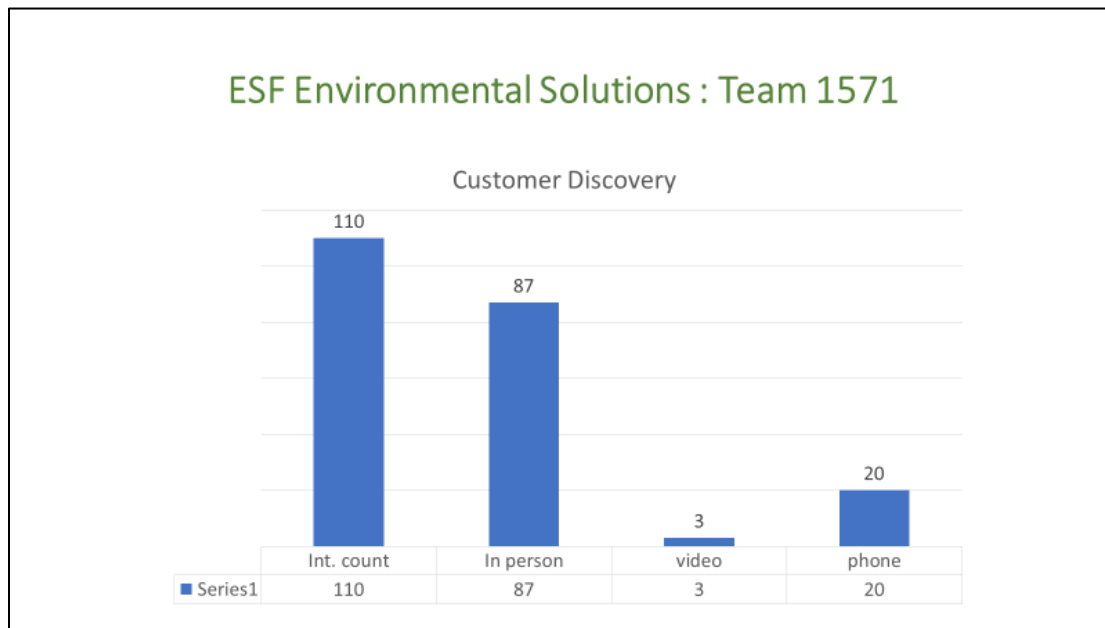


Figure 51: Final interview breakdown

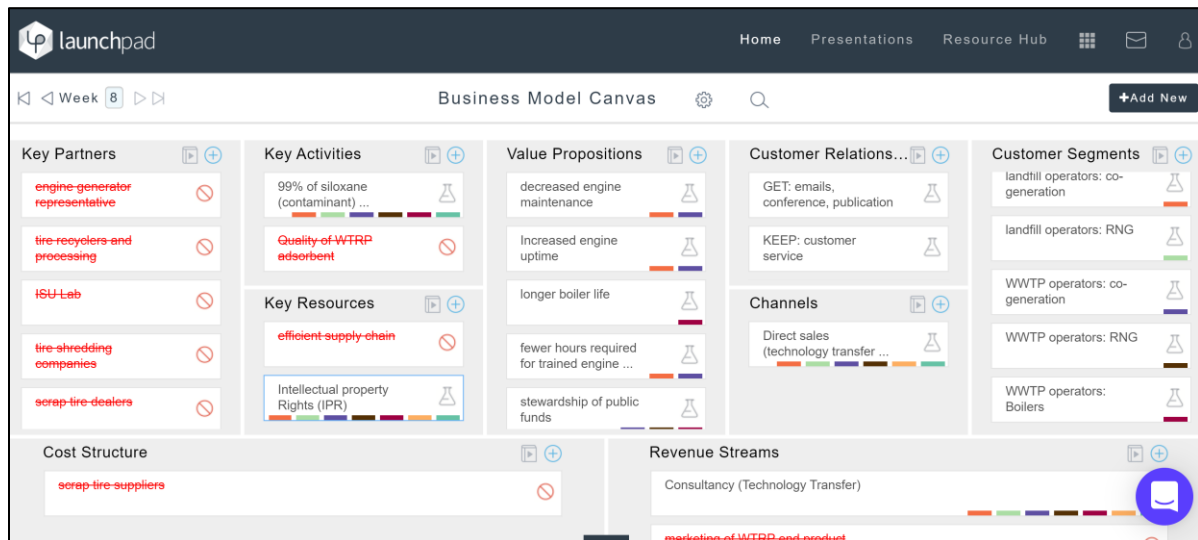


Figure 53: Final business model canvas week 8

Figure 54. shows the correlation developed by ESF Environmental Solutions between business thesis and value proposition.

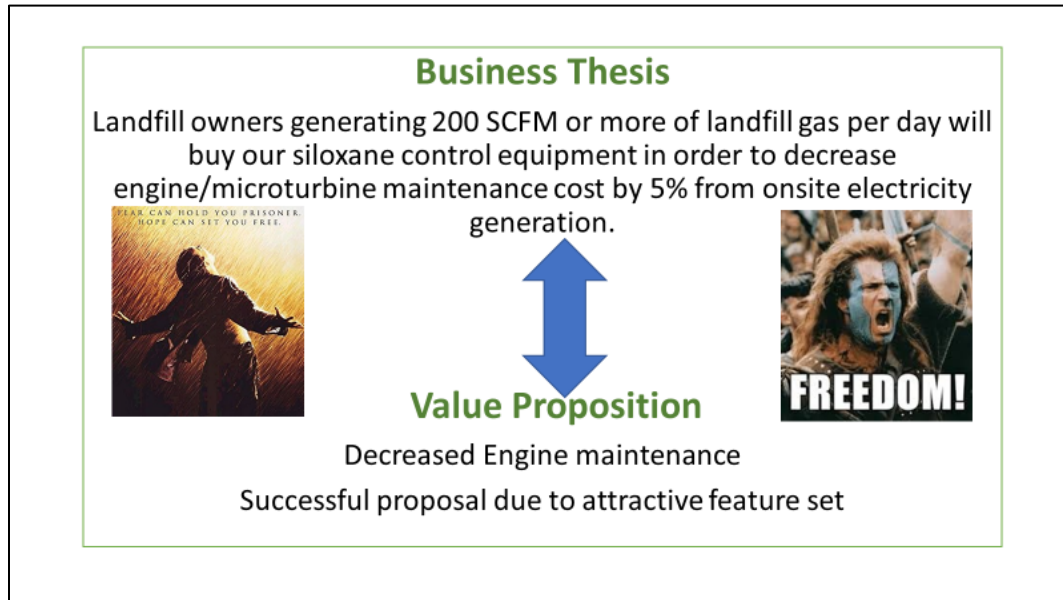


Figure 54: Final business thesis and value proposition

NSF National Innovation Corps (Spring Cohort 2019 - Important Findings and Data Insights)

The team “ESF Environmental Solutions” participated in the following NSF Innovation Corps Program: 2019 Spring Cohort Nashville, TN from May 5th - June 21st. A total of 110 interviews were conducted across 15 states in the U.S. of which 87 were in-person, 3-video, and 20-phone interviews. The customer segments (job specifications) which were explored between wastewater treatment plant (WWTP) and landfill gas to electricity industry included: landfill owners and operators, co-generation owners, operators, and maintenance staff, wastewater treatment plant operators, technical staff, maintenance personnel, environmental regulators at the local, and national level, consulting engineers, engine-generator manufacturers sales and marketing staff, renewable identification number (RIN) market analysts, and personnel for national biogas advisory groups.

Table 14. I-Corps Customer Discovery Interviews, 2019 (state wise and country wise)

State	Number of Interviews
U.S.	
Tennessee	7
Michigan	13
Wisconsin	3
Iowa	41
Nebraska	5
Minnesota	6
Missouri	2
Kansas	3
Illinois	5
Oregon	2
California	5
Maryland	1
Washington	8
Washington D.C.	1
New York	4
Video Interview	
India	4

Interview Question

The interviewees were asked the question, “What are the operational problems faced by your facility in renewable energy generation?” The most common value propositions summarized from the interviews are decreased engine maintenance, longer boiler life, stewardship of public funds, environmental responsibility, successful proposal due to attractive feature set, and reducing system capital cost. For pipeline injection a common response was uncertainty in the RIN market and ambiguous or changing gas quality standards imposed by local and regional gas authorities. One facility in particular had been injecting digester gas into the regional pipeline for decades, but when they decided to pursue RIN credits for the gas, the gas utility decided a stricter gas quality was required.

Table 15. Interviewee Industry Role

State/Country	Designation
Tennessee	Co-founder General Manager Field Office Manager Engineer Sr. Program Manager Emerging Technologies Senior Operations and Maintenance Consultant Technical Staff
Michigan	General Manager Plant Operator Manager Consulting Environmental Engineer Senior Engineer Operations Manager Operations Staff Engineer Landfill Operator Co-owner
Wisconsin	Founder Operations staff Environmental Research Manager
Iowa	Principal Director Vice-President Superintendent Maintenance Tech Environmental Consultant Engine Operator General Manager Operations Engineer Sales Engineer Engineer Manager Utility Supervisor Environmental Manager Plant Superintendent Senior Engineer CEO

	Biogas Lead Operations Staff Operator Plant Manager General Manager Lab Supervisor Plant Operator Project Engineer Operational Efficiency Lead Vice President (Operations) Principal/Vice President President Supervisor Water Resources Group Leader General Manager Sales Engineer
Nebraska	Director Associate Plant Manager Engineer
India (video-call)	Freelancer Director Project Engineer Maintenance Engineer
Minnesota	Maintenance Staff Mechanical Specialist Superintendent Plant Operator Superintendent Industrial Sales Manager
Missouri	Engineer
Kansas	Engineer
Illinois	Superintendent Region Engineer Plant Operator
Oregon	Engineer
California	Engineer General Manager Vice President
Maryland	Engineer
Washington	Energy Manager Operations Engineer Principal

	Process Analyst Mechanical Supervisor Engineer
Washington D.C.	Executive Director
New York	Engineer Environmental Engineer Project Process Mechanical Engineer

Understanding Customer Needs

The responses recorded in the 110 interviews are an indication to the extent of which siloxane, over the last two decades, has displaced hydrogen sulfide (H₂S) to become the primary nuisance in digester and landfill gas to energy projects. The responses made it explicit that siloxanes are considered as an adversary since they increase the maintenance costs of engine-generators, reduce energy output, and delay the payback period on capital costs.

Best aha !! moments which provided our Team with invaluable data

Table 16. Pupils dilating statements during customer discovery interviews

Sr. No.	Aha !!!! That's the data we have been waiting for
1.	Engines running on clean gas are rebuilt every 40000-60000 hours with 'Siloxane' that shortens 7000-8000 hours.
2.	Electricity reimbursement rates drive decisions on how the gas is utilized.
3.	In Atlanta BMW has a manufacturing plant. They use landfill gas to consume the heat. They transport landfill gas from a distance of 9 miles to consume at site. The example was given to show that transportation over long hauls is possible only for large conglomerates.
4.	Ames being a student town, students use beauty products and shampoo which is responsible for siloxane ending up in waste streams.
5.	Utilization companies have different standards for quality of renewable natural gas. The path from biogas to RIN is the longest one.
6.	RIN credits are driving the decision to purify biogas to pipeline quality, if RIN market collapses, they will use engine generators to produce electricity like they are currently doing.
7.	RIN credits is a huge market. It is 10 times the size of natural gas itself.
8.	What we are expecting from siloxane removal technology is a means to keep our output consistent and our maintenance costs minimum.

9.	At least 3 million cubic feet should be the gas generation per day for the project to be economically feasible. I have seen it with my own eyes except the mounting bowels for engine that hold the engine together, the entire engine parts are eroded because of sulfides and siloxanes.
10.	Low hanging fruit is existing landfills and anaerobic digesters that are already producing biogas, and the most profitable opportunity is to clean the gas for RNG.
11.	RIN market is driving economics as is carbon reduction/carbon neutral programs.
12.	Target for the renewable fuel standard is 36 billion gallons by 2022 (we are at 19 b now), ethanol is at a mature stage, biodiesel is capped out, and RNG can bridge the gap between where we are now and where we need to be.
13.	Renewable fuel credits are difficult to navigate and entities (like landfills and WWTPs) will need an advocate to help navigate those complexities. We are at the infancy of this market opportunity.
14.	Renewable fuels incentive program is driving a lot of projects and there is no shortage of financing for new projects if the economics can be demonstrated.
15.	The complexity of the gas cleaning systems represents a challenge for WWTP operators.
16.	Complexity of systems and workforce training are big issues as labor market is tightening. Risks are manageable, but typically assumed mostly be the developers.
17.	Siloxane buildup in the engines can still occur even with a siloxane removal system.
18.	A lot of cogeneration systems aren't operational now due to maintenance issues. Over design can be a problem for system optimization.
19.	Almost always provide gas cleaning equipment (which is a major cost of the project) to remove H ₂ S and siloxanes to protect engine generators.
20.	Siloxane problem was first realized in the 90s and affects every project (some are worse and have seen engine last for only 1000 hours). College towns seem to have more siloxanes.
21.	Our landfill site gas capacity is at present 1200 CFM, we need at least 1500 CFM for feasibility and early payback period.
22.	<ul style="list-style-type: none"> • Need 100 SCFM for vehicle fleet projects and 200 SCFM for RNG and Cogen projects, although many new projects are dependent on State or Federal grant funding. • Developers like to see 500 SCFM of gas before they'll consider a project. RNG projects are more desirable for developers due to the economics. Biggest cost is gas cleaning, but there are other costs and fees to consider as well (marketing, commissions, contracts, etc.)
23.	Till the time our boilers was running of natural gas it was absolutely fine. Once we started using digester gas and then maintenance issues started within a span of 2 years.
24.	Industry has two options. Economical technology for gas pretreatment or having corrosion resistant boilers.
25.	In addition, once you burn biogas in an engine you lose 65% of the energy content as heat. Whereas if you put it in the pipeline you only lose about 5% of the energy through the cleaning process.
26.	<ul style="list-style-type: none"> • Accountability of U.S. tax payers money is important. How would the people be convinced that the facility will generated an xxxx amount of money per kWh.

	<ul style="list-style-type: none"> How would the people be convinced that the company is going to be around the whole time?
27.	Landfills have created socioeconomic impact on the society. Landfill gas is perceived as a dirty gas and not worthy of electricity generation.
28.	"Cost" and "Distribution" are the two biggest challenges.
29.	We can see the gas burning in the boilers from the transparent enclosure. If the flume of the gas is orange then the gas is dirty quality. If the flume of the gas is blue then the quality of the gas is good.
30.	The injection point would require 3500 linear feet of gas pipeline which was expensive.
31.	Pipeline project was scuttled when it was realized pipeline injection triggered EPA and OSHA regulations that were particularly burdensome. Cogen offers benefits beyond environmental credits, including usable heat and reliable, self-sufficient energy production.
32.	Pipeline quality standards (specifically siloxane) in CA are a significant barrier to RNG adoption and has led CA to go to vehicle fueling stations and cogen options to take advantage of grant money and environmental credits.
33.	Technology will get RNG and cogeneration closer to cost-effective with NG.
34.	Economics are the driving force behind any gas to energy system under consideration. Having a side benefit such as digester heat or RIN credits can help move a project forward.
35.	Emissions regulations are a big challenge for the engines which now have catalytic converters to meet the regs. H ₂ S and siloxane removal is required to prevent fouling of the catalytic converters.
36.	Siloxanes are a problem for the engines and cause damage. Maintenance schedules could be extended if it weren't for siloxanes.
37.	Life of cogeneration heads could be extended if they had a siloxane removal system. It costs \$50,000 to replace heads every 10,000 hours.

CHAPTER 5. RIN CREDITS -THE BIGGER PICTURE: THE DRIVING FORCE FOR BIOGAS PURIFICATION IN U.S.

Once our group had a clear value proposition of decreased engine maintenance which was common for all of the customer segments interviewed through week 4, we focused our attention on the driving force to purify biogas in U.S. market. RIN credits issued through EPA and other financial incentives offered by the federal, state, and local governments can provide a lucrative incentive especially for pipeline injection projects where the upgraded digester/landfill gas can be tied to a transportation fleet that uses liquified natural gas. The interviews with environmental consultants and RIN market analysts helped our team broaden our understanding of the RIN market. Monetization of the environmental attributes of the RNG produced is driving the RNG projects which in turn has created the market need for a cost-competitive siloxane removal technology to make the process financially viable (I-Corps Customer Discovery Interviews, 2019).

Barriers to biogas upgrading include the absence of a national standard for pipeline quality gas. Utilities have the authority to make their own standards for gas quality entering the pipeline. Often these standards are quite strict and include low limits on total siloxane concentration entering the pipeline, online monitoring requirements, and automated provisions for gas diversion in the event the gas quality falls below the standard at any time. There may also be jurisdictional issues regarding pipeline injection that need to be overcome. National trend is developing in U.S. of repositioning the assets producing biogas into facilities which produce renewable fuel. The presence of RIN credits, the California Low Carbon Fuel Standard (LCFS) credits, Oregon Clean Fuel Program credits, and rapidly developing voluntary carbon markets, has driven the interest in converting biogas to renewable natural gas and injection into a commercial natural gas pipeline. Generating RINs and LCFS credits combined with the

commodity value of the natural gas can lead to very attractive payback periods, in often less than 3 years. Depending on the feedstock used to generate RNG (cellulosic or non-cellulosic), values of the RNG produced can range from \$9 to \$80 per MMBtu (Pliema, 2019). RIN credits are driving the decision to purify biogas to pipeline quality. Credits and incentives are an important part of the economics of a project. One of the consultants based in Des Moines, IA during an interview said that the “low hanging fruit” is existing landfills and anaerobic digesters that are already producing biogas, and the most profitable opportunity is to clean the gas for RNG to take advantage of the RIN credits and other available incentives. This is often more economically viable for new projects since cogeneration does not have the same opportunity for credits and incentives despite being a renewable form of energy. One of the consultants with a large environmental company interviewed in Omaha, NE during an interview said that, when biogas is used in boilers or for co-generation the payback period can often exceed 15 years. However, if it is used for pipeline injection as renewable natural gas (RNG), the payback period can be shortened to as little as 5 years, which is attractive to investors willing to take the risk that the RIN market will be stable over that time period. The target for the renewable fuel standard (RFS) is 36 billion gallons by 2022 (we are at 19 billion now). Ethanol is considered to be at a mature stage, and the economics of biodiesel have limited its contribution, leaving RNG to bridge the gap between current production and the target 36 billion gallons. RNG has grown from 150 million gallons in 2016, to 305 million gallons in 2018, and 400 million gallons in 2019. The goal is 1 billion gallons of RNG by 2022 (NSF Innovation Corps - customer discovery interviews, 2019). The associate was of the opinion that RNG can shore up the profitability however, payback period plays a crucial role in adaptability. Wastewater treatment plants and municipal landfills are moving from strictly compliance entities to resource and energy recovery

entities, and RNG is at the infancy of this market opportunity. Only in the last 5 years has pipeline quality gas been seen as a profitable endeavor due to the renewable fuel standard and credits. The biggest obstacle for waste to energy projects is the gas quality and gas cleaning requirements which tend to drive the economics of the project. Key technical breakthroughs will lower technology costs and allow RNG and cogeneration to be more financially viable. Providing a cost-competitive siloxane removal technology will allow RNG and cogeneration to better compete with natural gas and utility electric rates. RNG from biogas has a huge advantage over wind and solar in that it is dispatchable, i.e. it can be turned on or off depending on the demand. Additionally, electricity storage is not required, only gas storage. A process innovation for biogas pre-treatment originating in the U.S. would be ideal to meet the economic requirements of a digester biogas or landfill gas conditioning system for the removal of siloxanes and other contaminants.

Figure 55. shows the original volume requirement for each specific category of fuel by year. It can be seen from the figure that cellulosic fuels (biogas) is showing a consistent increasing trend every year compared to the other three categories which are showing a constant output.

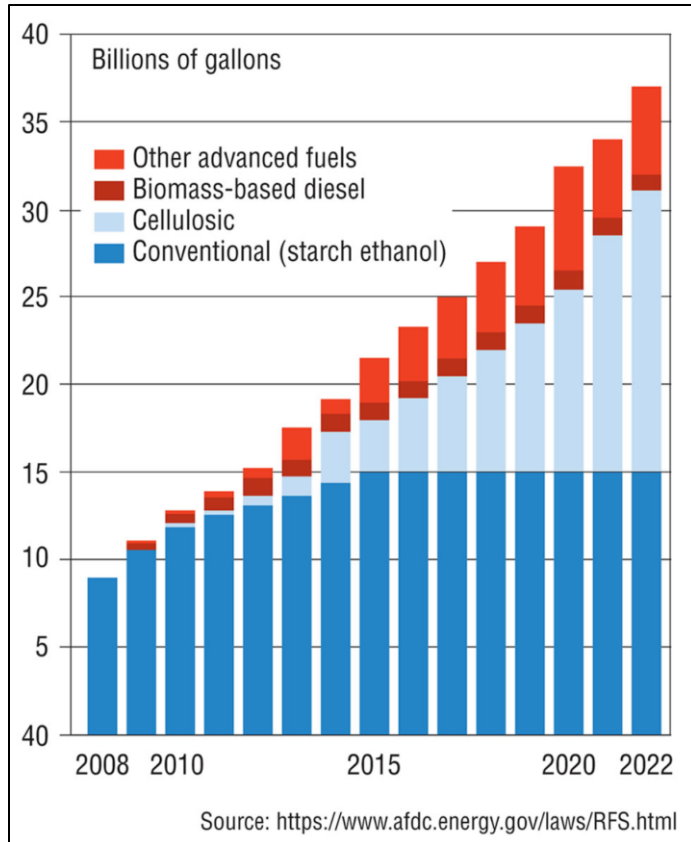


Figure 55: RFS volume requirements by year (2008-2022) (Pleima, 2019)

From Figure 56, it can be seen that biogas falls under D3 category RINs which have higher value as compared to D5 category due to supply constraints.

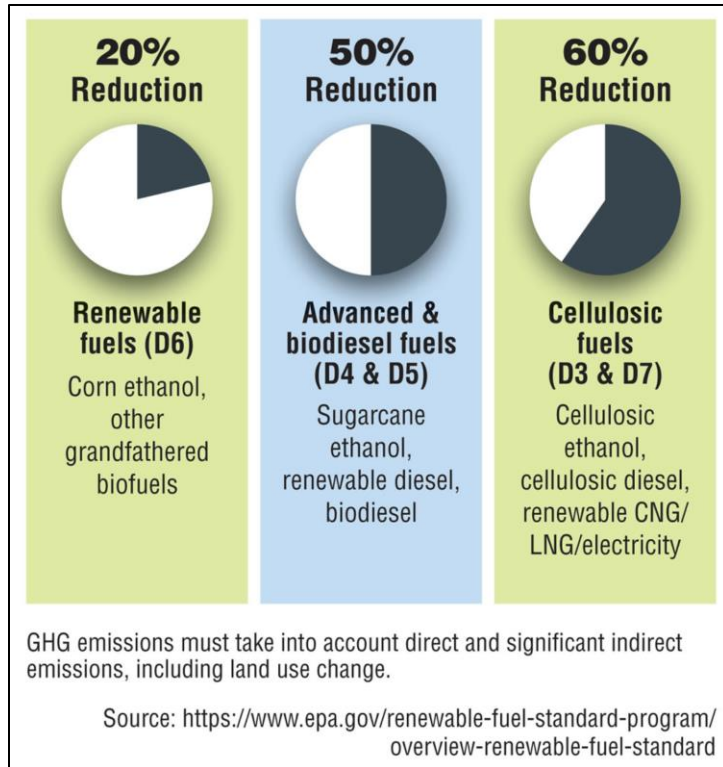


Figure 56: Greenhouse gas emission reduction by fuel type (Pleima, 2019)

CHAPTER 6. NAVIGATING THE WAY FORWARD

Once our team became absolutely sure of the value proposition and the presence of RIN credits and other environmental incentives driving the biogas industry, we became confident of our applied research plan. In addition, after studying the target market our team realized the opportunity which lies ahead through the RIN market which is still in its adolescent stage. We realized that our research plan of evaluating siloxane removal efficiency from biogas using waste tire rubber of three different sizes, to identify design and operating conditions that lead to not less than 98 percent siloxane removal efficiency and a siloxane concentration in the outlet gas less than 0.1 mg/m^3 and developing a marketable tire reuse technology that achieves a capital and operating cost of 50-80% of using activated carbon has the potential to address the markets needs with reference to the previous experimental results (Seifers, A. 2010).

There are approximately 14,748 municipal and industrial wastewater treatment plants in the U.S. (Center for Sustainable Systems, 2019), but not all have anaerobic digestion producing biogas. However, there are an additional 14,000 sites where biogas to electricity systems are feasible as per ABC estimates (I Corps Customer Discovery Interviews, 2019). EPA's Landfill Methane Outreach Program (LMOP) indicates that there are 2000 active landfills in the U.S., of which 953 have active landfill gas to electricity projects. Our innovation of siloxane pretreatment technology has dual benefits. It is an economic adsorption technology which would have mass acceptance from the industry as addressed above. Secondly, the manufacture of waste tire rubber particles as an adsorbent media would compete with activated carbon (AC) which is an expensive adsorbent. The total available market for biogas is estimated to be approximately \$1.3 billion, the served available market is \$ 675million, and the target market for our proposed technological innovation is \$200 million. The target market value was estimated by our team

(ESF Environmental Solutions) considering the existing market constituents and the void in the market for competitive technologies.

Many landfills are located in economically disadvantaged and/or rural communities due in part to the NIMBY (not in my back yard) phenomenon where the property values are depressed and the communities may not have a significant voice in how the landfill is operated, how vehicles access the landfill site, how litter from the landfilling operation is controlled, or how odors emanating from the landfill are mitigated. By providing an economical solution to siloxane control as well as creating a reuse option for waste tires, the well-being of these communities will be improved, more landfills will capture gas for electrical generation, and uncontrolled emissions, including greenhouse gases, will be reduced. The American Biogas Council (ABC) anticipates that there are approximately 14,000 proposed locations where biogas to energy systems are feasible and make economic sense (ISU, 2019).

More wastewater treatment plants are striving to meet their own energy requirements with renewable energy from biogas. One of the big drivers for development is the Renewable Fuel Standards (RFS) which had an original target goal for 2022 that 20% of all transportation fuel come from renewable sources. This schedule would have required 26 billion gallons in 2019, but we are well below this goal. In light of this shortfall, the US EPA sets a yearly renewable volume obligation which specifies the amount of renewable fuel to be blended with the total production. In 2019 this volume was just under 20 billion gallons (Pleima, 2019). Currently, biogas is only meeting about 300 to 500 million gallons of the renewable fuel market (less than 2.5%), so the opportunity for biogas to provide a larger portion of the RNG market is substantial. The sustainability of the process is also a consideration, and a technology that uses a

waste product (tire rubber) to help convert another waste product (biogas) to renewable energy has broad appeal.

Limitations of current technologies

The most frequently used method for removing siloxanes is adsorption on activated carbon. In common units, activated carbon is used to reduce the siloxane content, but since siloxanes are difficult to desorb from the material, these adsorbent beds need to be replaced regularly. At a landfill in Trecatti, South Wales, for example, a weekly change of the activated carbon is necessary, with a one-day downtime at the adsorber and a cost of approximately \$2800 per change (Dewil et al., 2006). Activated carbon media for siloxane removal incur significant replacement and maintenance (ISU, 2019). Other possible adsorbents/removal technologies include silica gel, molecular sieves and polymer pellets. The main disadvantage of current technologies have in common is the high operating costs related to replacement and disposal of spent adsorbent.

Intellectual Property (IP) Landscape

Most siloxane adsorbents used currently are proprietary in nature and are covered by intellectual property protection. It is anticipated that the development of a successful siloxane adsorbent using tire rubber particles will also necessitate intellectual property protection. IP protection may include several elements of the scrubber design and operation (including sizing, configuration, baffling, etc.), methods for adsorbent regeneration, processes for preparing spent media for reuse in alternative systems, and tire media preparation techniques. Currently there are a variety of U.S. patents for the use of recycled tire rubber including its incorporation in asphalt, pyrolysis to produce fuel, building blocks containing up to 15% recycled tire material, and devulcanization to produce tire-derived polymer. Project execution will include reviews of process methods and equipment that would warrant IP protection. Novel material processing

that improves economics and efficacy of the adsorbent, as well as those that enable re-use of spent adsorbent, will also be considered for IP protection.

Prototype Development and the way Forward

110 interviews spread across 15 states in the U.S. provided diversified data of the market expectations in terms of technological innovation and economic requirements. The prototype (product development) would be developed through Partnership for Innovation (PFI) - Technology Translation (TT). Product development phase is very crucial as it would form the main R&D part of the proposed project. R&D results which further finds sufficient traction in the industry would be commercialized.

The proposed study involves development of process technology as well as development of an adsorbent waste tire rubber material used as a removal media in scrubbers for contaminant deposition. Once the prototype for the technology is ready then commercialization would commence.

Spin-Out Company

Initial plan of our team “ESF Environmental Solutions” is to have a spin-out company. The biggest resource for our team is Iowa State University Research Park (ISURP) which is an incubator for new and expanding businesses. ISURP also provides access to the vast array of resources available at Iowa State University: from talent pipeline management, to specialized equipment, to access to the research infrastructure. Major difficulties facing a spin-out company, such as raising capital, managing growth, and penetrating new markets, revolve around business rather than technological concerns can be effectively addressed through University and trusted commercialization partners (HDR, CDM Smith, Jacobs etc.).

Technical Challenge and Applied Research Plan

The following variables would be tested that control the site conditions (in-situ) for the proposed study: empty bed contact time, amount of tire rubber media, type of tire rubber media, compaction of media, temperature, concentration of the inlet gas and, pressure. These have all been studied in depth for the removal of hydrogen sulfide from biogas in previous work (Siefers, 2010; Wang, 2010, Wang et al., 2013; Wang et al., 2014) but not for siloxane removal. A theoretical framework will be created for the proposed research for testing of siloxane (D4 + D5) removal using waste tire rubber material under different operational conditions in comparison to activated carbon.

Waste tire rubber material will be prepared as in previous studies on H₂S removal (Siefers, 2010, Wang, 2010). Particle size analysis will be conducted to ensure an effective particle size for adsorption with the necessary surface area. Three types of rubber media will be prepared and tested with regard to particle size and composition. Metal composition (primarily Zn and Fe) was shown to be an important factor in H₂S adsorption. It is conceivable that the carbon black composition will be a more important factor in siloxane removal than metals, but that is yet to be determined.

Experimental data has shown that increasing the pressure of the adsorbate in the gas stream causes a higher amount to be adsorbed (Siefers, 2010). Increases in the temperature of the adsorption systems have been found to decrease the amount adsorbed, and therefore it is usually desirable to operate an adsorption system at as low a temperature as possible. Additionally, it has been found that adsorption improves with an increase in the molar mass of the adsorbate. If desorption and regeneration are possible, the economics of performing this process should be

compared to disposing of the spent material and purchasing virgin material. As the virgin material for our study tire rubber particles are derived from a waste product, it may be more economical to use virgin material as opposed to regenerating the spent material. This specific part of the study would be the most interesting as the quantity of material for a certain amount of raw biogas treated would be compared between activated carbon and tire rubber. The process of desorption and regeneration and the comparison to virgin tire rubber material would give us quantifiable data about the economic benefits of using tire rubber in comparison to activated carbon. Additionally, it would be determined if the spent tire rubber particles can be used in other applications, such as an asphalt modifier or in molded products, as crumb rubber and micronized rubber (e.g., from LeHigh Technologies) is used. The investigators are also looking into the use of spent tire rubber as a reducing agent in denitrification systems, e.g., to remove nitrates in tile drainage. This tertiary application of spent tire rubber would further the objective to make beneficial reuse of end products in pursuit of a circular economy that eliminates waste.

Future Commercialization Strategy

Five phases guide the new product development process for small businesses: idea generation, screening, concept development, product development, and finally, commercialization. The phase of idea generation led to the participation at ISU I-Corps in Feb-March/2018. Twenty-eight landfill operators were interviewed as a part of validating the hypothesis that siloxane control is a major issue at landfill sites, especially those that use the gas to generate electricity. The confirmation bias through the interviews resulted to further applying for NSF Innovation Corps Program. The phase of screening and concept development was further completed through participation in NSF Innovation Corps Program:2019 Spring Cohort Nashville, TN. 110 interviews spread across 15 states in the U.S. provided diversified data of the market

expectations in terms of technological innovation and economic requirements. The prototype (product development) would be developed through Partnership for Innovation (PFI)-Technology Translation (TT) track. PFI-TT supports commercial potential demonstration projects for academic research outputs in any NSF-funded science and engineering discipline. This demonstration is achieved through proof-of-concept, prototyping, technology development and/or scale-up work. Product development phase is very crucial as it would form the main R&D part of the proposed project. R&D results which further finds sufficient traction in the industry would be commercialized.

CHAPTER 7. ENGINEERING SIGNIFICANCE

The Societal Need and the Customer

Currently in the U.S. there is a tremendous market potential for the utilization of digester and landfill gas by converting it to both electricity and pipeline quality renewable natural gas. There are a plethora of opportunities in the market in the form of economic benefits through co-generation, renewable identification number (RIN) credits through renewable natural gas (RNG), and low carbon fuel standard (LCFS) credits. Construction of new facilities will create thousands of jobs for engineers, architects, designers, construction personnel, etc. An effective technology for pretreatment of biogas for siloxane removal can help to stabilize the renewable energy market. Eliminating or minimizing the obstacles that siloxanes pose will allow for decreased engine maintenance, feasibility for meeting pipeline injection standards, and a more lucrative payback period for new and existing gas to energy facilities.

The Innovation

Our innovation will lead to the development of an economic siloxane adsorption technology using waste tire rubber particles as the removal media (adsorbent) in scrubber column placed in-situ. The novel part of this technology is using waste tire rubber as the adsorbent and demonstrating its use as a cost-effective alternative to activated carbon, silica gel or other siloxane removal technologies. Prior research has shown that the smaller sized particles (less than 1 mm) have significant adsorption potential and could compete with activated carbon and silica gel as an adsorption media. Greater than 98% hydrogen sulfide removal was consistently obtained in a demonstration project at the Ames Water Pollution Control Facility (Siefers, 2010). Preliminary experiments showed similar performance for siloxane removal and a full-scale installation of a tire rubber-based adsorption systems was estimated to have a

payback of approximately 2 years compared to over 9 years for an activated carbon-based system. The goal of the proposed research is to verify the process economics and removal efficiency of the rubber particle system and demonstrate a consistent performance that meets the siloxane concentration requirements for both direct pipeline injection and engine-generator specifications. Waste tire rubber is proposed as the ideal media since it has been shown to have adsorptive properties, it represents a waste product, and is in abundant supply (currently only 81.4% of waste tires are recycled in the U.S. according to a study by the U.S. Tire Manufacturers Association (USTMA, 2019)).

The Value Proposition

Our innovation is aimed at creating an economic process for the pre-treatment of biogas, specifically for siloxane removal using scrap or waste tire rubber particles. Prolonging the engine life and meeting pipeline siloxane requirements will create a definitive path for the generation of cost-effective electricity in competition with natural gas and other thermal means. Utilization of discarded tires for this purpose will create an additional market potential for this underutilized resource. Current use of waste tire rubber is mainly for crumb rubber for sports fields, playgrounds, landscaping, asphalt modification, molded products, and drainage applications. Adoption of waste tire rubber for siloxane removal media will provide an additional beneficial reuse opportunity for this waste material.

CHAPTER 8. CONCLUSION

Energy conversion systems (IC engines/microturbines) for biogas are much more sensitive to siloxanes than for hydrogen sulfide. Customer discovery through ISU I Corps and NSF Innovation Corps validated that removal of siloxanes prior to energy generation is a necessity.

Future research should be focused on the following four success metrics:

1) Meeting engine/microturbines siloxane limits

Different engine and microturbine companies have specified siloxane limits. Meeting the optimum limits would ensure the reduction in maintenance and downtime of the equipment.

2) Meeting pipeline injection requirements

RNG requirements for pipelines are stringent in nature. Meeting the requirements would ensure the success of the economics involved in the process. Meeting requirements along with cost parameter fulfillment will be beneficial for the industry. This would encourage more capital investments in RNG.

3) Cost criteria (comparison of tire rubber media to activated carbon)

This parameter is the most important of all as it will decide the process costs of the adsorbent product. It is also directly related to the manufacturing (business) part of the research.

4) Removal efficiency (%) of siloxanes

It would be achieved through continuous iterations with the design and operating conditions to achieve the desired result.

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